UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

PROGRAMME:

Bachelor's degree in Electrical Engineering

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FINAL DEGREE PROJECT TITLE:

"Diseño de una planta piloto para ensayo y monitorización de sistemas fotovoltaicos basados en KETs"

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DATE OF DELIVERY:

January 2020

ACKNOWLEDGMENTS

I would like to recognize and appreciate the performance of all people that have collaborated and worked in this huge project in which I have participated as a student and apprentice. Special mention to the people who have taught and support me in a selflessly way:

To the project manager Alvaro Luna, who has guided me along the project taking care that I received the most appropriate knowledge to my development as engineer.

To the researcher Salim Bouchakour, the person with whom more hours I have shared and who with great patience more has taught me.

To Borja García, Joan Rocabert, Jose Ignacio Candela and the entire SEER staff who have resolved so many doubts.

To Ibrahim Hajira, Sidi Mbarec and Ayoub, students from IES Santa Eulalia institute, who actively have worked in the assembly.

Finally, special thanks to my family, who have supported me unconditionally during, before and after this project.

DECLARATION OF HONOUR

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Title of the Thesis: **Diseño de una planta piloto para ensayo y monitorización de sistemas fotovoltaicos basados en KETs**

SUMMARY

This project develops the study of PV panels made with new technologies such as bifacial cells or EVA encapsulation method, and also placed in different ways like south, west and east facing. These panels have been placed on TR14 roof (Gaia building, ESEIAAT). The research starts with the PV panels' assembly and it finishes with the study of the data recollected. The process between the first and last step comprises many point to take care: Checking and installation of each component of the system (sensors, wires, PV panels, converters, storage system…) as well as the communication between them and the software programing in charge of recollect the information.

The whole analysis is based on the experimental point of view, following the chain of implementation of a system that consists of the stages of development, verification and implementation; evaluating functionality and interoperability with the user.

The first part of this document collects the information about the PV panels, placement and testing of their features. Then the project is focused in the installation and start-up of the system after the processes of verification, issues resolutions from sensors, PV panels, inverters and other components. We will see also the software programing in order to manage the system and specially the monitoring data to be studied in the future.

This project makes a lineal process tracing along the time but due the vast quantity of components and odds of failure of them there are some setbacks that have not been already solved. That is specified when are written in their corresponding sections.

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FIGURE LIST

Abbreviations And Acronyms

BAPV	building-applied photovoltaics
BIPV	Building-integrated photovoltaics
CSP	Concentrated solar power
DIF	Diffuse Horizontal Irradiance
DHI	Diffuse Horizontal Irradiance
DNI	Direct Normal Irradiance
EJ	oxyjoule, $1 \cdot 10^{18}$ Joules
ERDF	European Regional Development Fund (ERDF).
ESEIAAT	Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa
EVA	ethylene vinyl acetate
GHI	Global Horizontal Irradiance
KET	Key Enabling Technologies
MMPT	Maximum Power Point Tracker
MPP	Maximum Power Point
MPPT	Maximum power point Tracker
OECD	Organisation for Economic Co-operation and Development
PET	poly ethylene terephthalate
PV	Photovoltaic
PVB	Polyvinyl butyric
SEER	Renewable electrical energy systems

SI	*International System of Units*
TPO	Thermoplastic polyolefin elastomer
TPSE	Silicones Thermoplastic silicone elastomer
TSI	Total Solar Irradiance
UPC	Universitat politècnica de Catalunya

CHAPTER 1. INTRODUCTION

This document is part of a bigger project named "Sudoket" in which there are involved several universities and institutions that work in the research field. The conclusions, results and data of this project will give valuable information to determine the viability of new technologies like bifacial photovoltaic cells or the named "Building Integrated Photovoltaics".

SUDOKET has the main objective of driving growth around Innovative Buildings by boosting abilities of research and development of Key Enabling Technologies (KET) based solutions for these types of constructions in universities and research centers. This Project will promote the creation of links and synergies between constructors, manufacturers, designers and technologists, there by contributing to improve the quality and competitiveness of Innovative Buildings in Europe. SUDOKET project is co-funded by the "Interreg Sudoe Programme". Such programme is implemented in the frame of the territorial cooperation European objective, being known as "Interreg**"** and supported by regional policy funds (**ERDF)** [1]**.**

Figure 1. "Sudoket" logo

1.1. JUSTIFICATION

Prior to the Industrial Revolution period, in the mid-19th century, nearly all energy used was renewable, especially the hydraulic and wind energy. This energy has been used for many activities but they were replaced by more powerful and available energies like the coal energy [2].

After that the renewable energy research has been developed slowly without any big repercussion in the society since the 1970s when environmentalists promoted it as a replacement of the eventual depletion of oil, as well as a dependence scape from it. At that moment is when first electricity-generating wind turbines appeared [3]. This movement helped to discover the photovoltaic solid state effect in 1885 but solar energy had been just used for heating and cooling because PV panel were too expensive until 1980 when the first solar farm appeared [4].

The renewable energy has become popular in the last centuries, the developing of the solar energy, and generally the renewable energy, is consequence of several factors like the discovery of new materials, the awareness of the society towards the environment, cheaper materials, and the huge increasing of the electronical components and systems like computers or inverters that made the PV panel managing more easy and efficient.

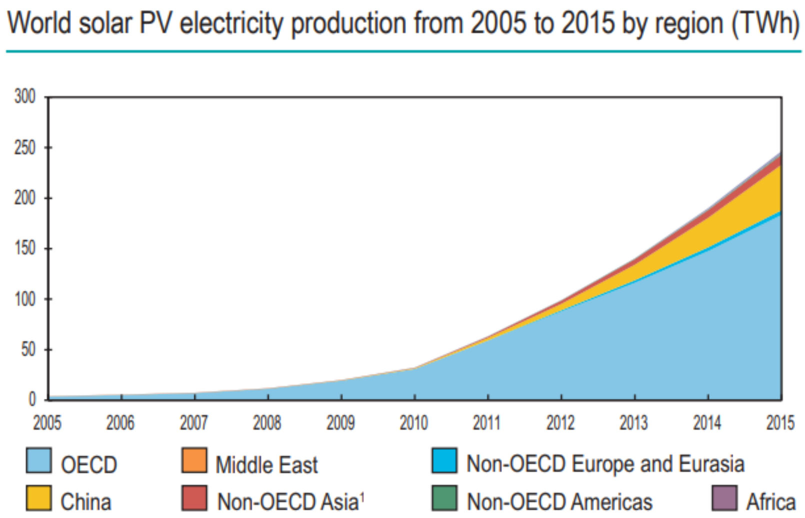

Figure 2. Solar photovoltaic electricity production in the world [5]

The actual situation is that every year is announced new technologies, materials or resources that make the solar energy cheaper, efficient and available to people that take advantage of the new situation and incorporate into their homes solar systems to be able to produce their own electricity amortising the investment in a few years while PV solar power plants are exponentially growing around the world.

All this teach us that nowadays solar energy situation is consequence of the research. This report is also another step in favour of the PV solar energy research.

1.2. SOLAR POWER POTENTIAL

The sun energy is the energy used to produce electricity through photovoltaics panels. The sun comprises about 99,86% of the mass of the Solar System and has a total global energy potential minimum of 1,575 EJ and maximum of 49,837 EJ, these values depend on the region of the earth [6]. In order to make these values useful for the solar panel study it is better to talk about solar irradiance average in SI units.

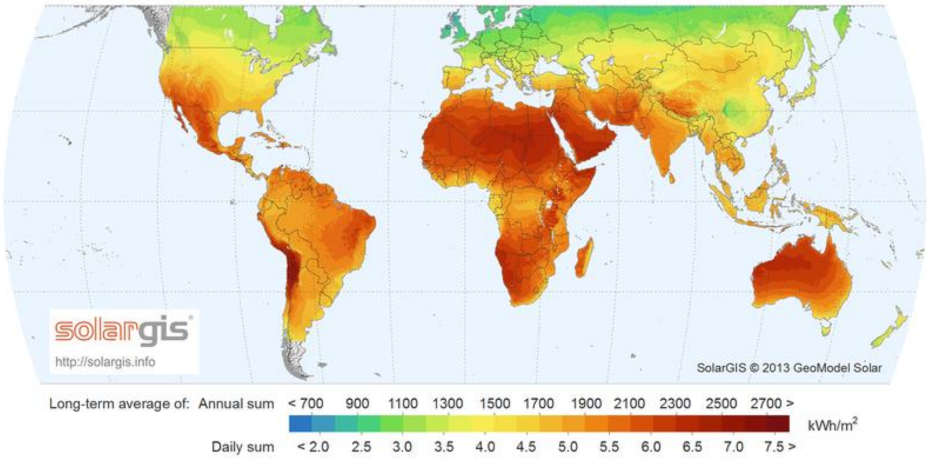

Figure 3. Energy solar average in the world [7].

We must distinguish several types of irradiance:

- **Total Solar Irradiance** (TSI) is a measure of solar power overall wavelengths per unit area incident on the Earth's upper atmosphere [8]. TSI average is 1361 W/m2 [9].

- **Direct Normal Irradiance** (DNI), is measured at the Earth surface at a location given by a surface element perpendicular to the Sun [6][10]. The sensor must track the sun through the sky in the way this is moving, due to that it is needed a solar track system.

- **Diffuse Horizontal Irradiance** (DHI or DIF), this is the DNI radiation scattered or reflected by atmospheric components [10] and not received in a direct way. This radiation would not exist without atmosphere; in that case we would just receive direct normal radiation.

- **Global Horizontal Irradiance** (GHI) is the total amount of shortwave radiation received from above by a surface horizontal to the ground. This value has particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI):

$$GHI = DHI + (DNI \cdot \cos\theta)$$

- **Albedo** is the radiation that any object reflects. Due to the PV panels features we are going to study (bifacial panels) is mandatory to know this type of radiation. All objects reflect radiation depending on the surface material, the surfaces that reflect a lot of radiation are named "cool" because the reflection of the radiation allows the object be cooler than other objects [11].

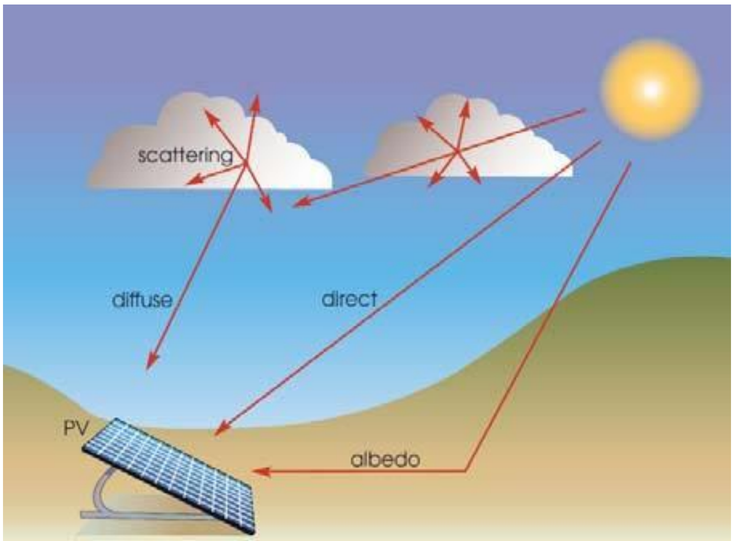

Figure 4. Scheme of radiations that PV panels receive [11]**.**

Although this project is just focused in the photovoltaic solar energy production it is also possible take advantage of the sun in other way, then it is summarized both systems:

- **Concentrated solar power** (CSP), it uses lenses or mirrors and tracking systems to concentrate sunlight and focus heat, then this heat is used to generate electricity by conventional steam-driven turbines [7]. It is interesting to be placed in locations that receives a huge amount of sun along the year because in those conditions is a relevant powerful power plant but needs a big investment in order to build the turbines building, the mirror field and its tracking system, due to that it is not viable to place on a small scale like houses, factories or other buildings.

- **Photovoltaic** (PV) employs photovoltaic panels which generate electrical power. PV installations can be mounted on ground, rooftops or walls. The panels can be fixed or use a solar tracker system to follow the sun across the sky. It doesn't need a big investment or infrastructure, basically it needs just a photovoltaic panel, inverter and connexion to work, despite that the system can be more complicated and also integrate several components like storage batteries depending on the energy production amount, for instance it is possible to find small power systems like charge sources for cell phones (around 5W) or big power plants like the "Noor Complex Solar Power Plant" in Morocco (160MW) [12].

1.3. THE PHOTOVOLTAIC PANELS

PV panels work thanks to solar cells, a certain amount of solar cells are assembled on the same flat structure and connected between them and their power depends on the solar cells amount. The ways that are connected (Parallel or series) defines the total intensity or voltage that the photovoltaic panel can delivery. If they are connected in series the voltage increases and in parallel connection is the intensity that increases. The connection is complicated, there are also bypass diodes in parallel between each cell in order to avoid the dark currents that appear when exist shades or other elements over the panel [13].

1.3.1. Solar Cells

First commercially viable silicon solar cell was created in 1954 in despite of the ability of some materials to create electrical charge from light exposure was first observed in 1839 [14]. The solar cells are made confronting two semiconductor materials slices, in fact is the same semiconductor but one slice has been chemically configured to have fewer electrons (p-doped), and the other has been chemically configured to have more electrons (n-doped). When a photon hit the p-doped surface some electrons are moved to the n-doped surface generating the electricity [15].

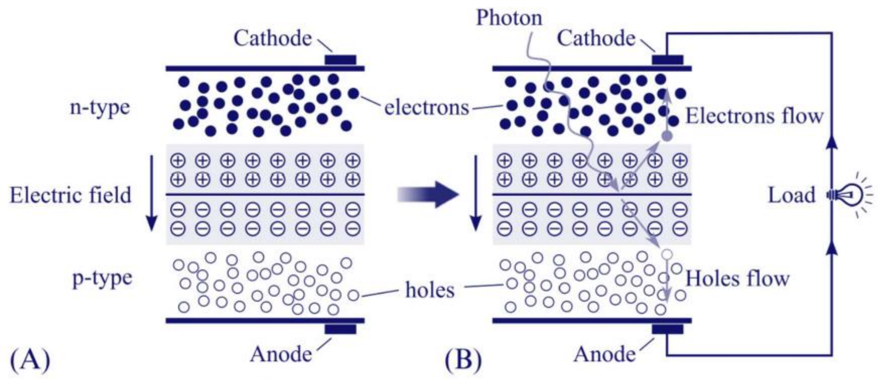

Figure 5. Photovoltaic cell running

The most used semiconductor material is silicon in different configurations, basically monocrystalline silicon and Polycrystalline silicon but are also used in a few cases Epitaxial silicon, Ribbon silicon …, each silicon type gives different properties to solar cells. Materials like Cadmium telluride or Gallium arsenide are also used.

1.3.2. Encapsulation Methods

In order to protect the cell they are encapsulated between two surfaces, frequently one of them is glass or polyvinyl acetate and the other one is a material like polyvinyl fluoride, PVF, poly ethylene terephthalate (PET) or metal. If the PV panel is a bifacial cell, both surfaces are made with glass and polyvinyl acetate because are transparent. To fix the cells between the surfaces is added a material, this material is very important and determines the final properties of the panel. This material is named encapsulation material.

The encapsulation material used in photovoltaic modules production must satisfy several requirements to reach the optimum performance, which include: high optical transmittance of incident light, good dielectric properties (electrically insulating), mechanical compliance to protect the solar cells from external mechanical loads and stresses induced by differences in the thermal expansion coefficients, good adhesion to both glass and silicon solar cells and resistant enough to withstand 20 – 30 years under any weather condition [16].

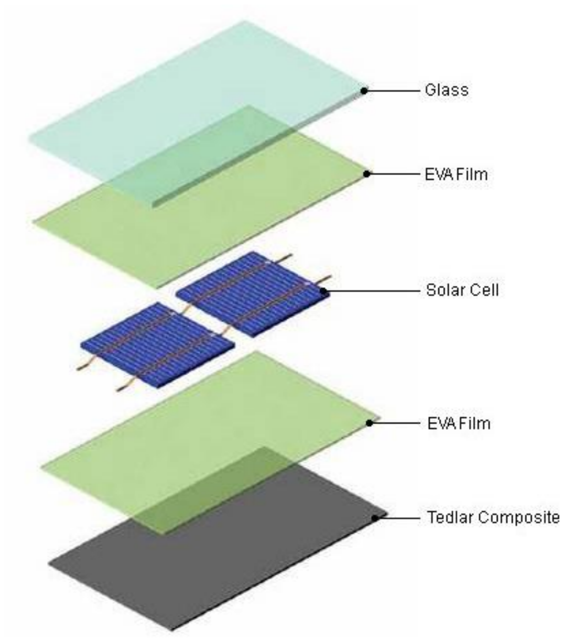

Figure 6. EVA encapsulation method

Since the 1980's, the encapsulation method used in almost all solar modules has been the copolymer ethylene vinyl acetate (EVA) but other material are also used, such as polyvinyl butyric (PVB), Silicones Thermoplastic silicone elastomer (TPSE), Thermoplastic polyolefin elastomer (TPO) and Ionomers [17]. Although EVA is the most used material, TPO could be its substitute in the future due to the fewer prices.

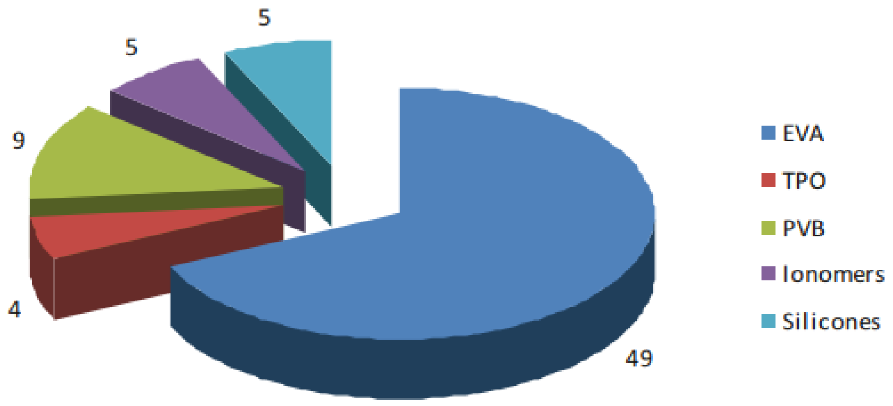

Figure 7. number of products in the different materials [18]

1.4. PV PANEL FEATURES

The most important PV panel characteristics are: efficiency, curve V-I and the degradation along the time. These characteristics depend on how the PV panel has been made. They have been explained in the following sections but there are also other features to consider according with the European standards that are related in the following publications [19]:

- IEC 60904-2, Photovoltaic devices Part 2: Requirements for reference solar cells.
- IEC 60904-6, Part 6: Requirements for reference solar modules
- IEC 61194, Characteristic parameters of stand-alone photovoltaic (PV) systems
- IEC 61829, Crystalline silicon photovoltaic (PV) array On-site measurement of I-V characteristics

1.4.1. Performance

Commercialized solar panels performance is about 5% and 25%. This performance range is large enough to exploit the massive, free and endless sun energy. The efficiency is also nowadays in evolution and development [20].

PV panel performance also depends on the situation, orientation and how is placed, for instance if the panels have a track system the performance rises considerably.

Panel cell technology	Efficiency (%)
Monocrystalline silicon	12-18
Polycrystalline silicon	4-9
Amorphous silicon	Up 11
Bifacial PV panel	18-30

Figure 8. Some technologies performance [21]

1.4.2. V-I curve

The V-I curve determines how the PV panel works depending on the temperature and the irradiation that the panel receives. The V-I curve is the most important feature to know where is the point of maximum power (MPP) depending on the panel and the weather features so the inverter can manage the PV panel.

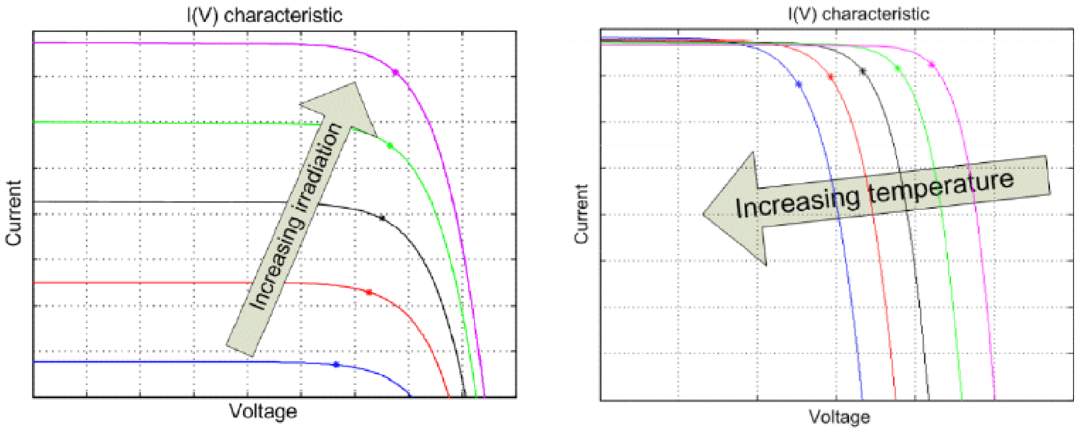

Figure 9. V-I curve variation depending on the temperature and the irradiation [21]

1.4.3. PV panel degradation and tests

Panel degradation changes the curve V-I along the years decreasing the PV panels performance. Nowadays there are panels with 30 years of useful life and guarantees about 20 years.

According with the European standards there are several rules in order to determine the panels useful live:

- The IEC 61730-2 [14] and UNE-EN 61345:1999 establish the tests that the PV panels have to pass in order to determine the useful life depending on the UV radiation received [21].

- IEC 61730-2 also establish the tests that the PV panels have to pass in order to determine the temperature cycling life [21].

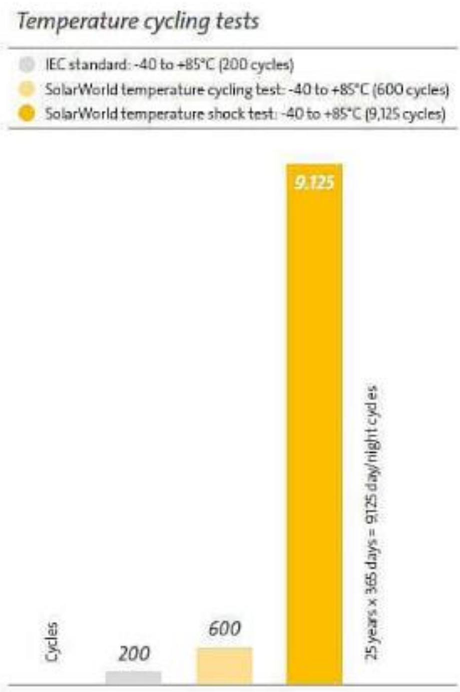

Figure 10. Temperature cycling test [22]

1.4.4. Other PV panels properties and tests

The panels must also pass some tests related with hits, pressures or corrosion that are regulated by European standards:

- IEC 61730-2: The IEC standard, for hail resistance, requires an impact from 4 meters, with a steel ball of 25mm and 7.53gr.
- UNE-EN 61701: 2000: Corrosion test.
- IEC 61730-2: Pressure test for wind and snow.

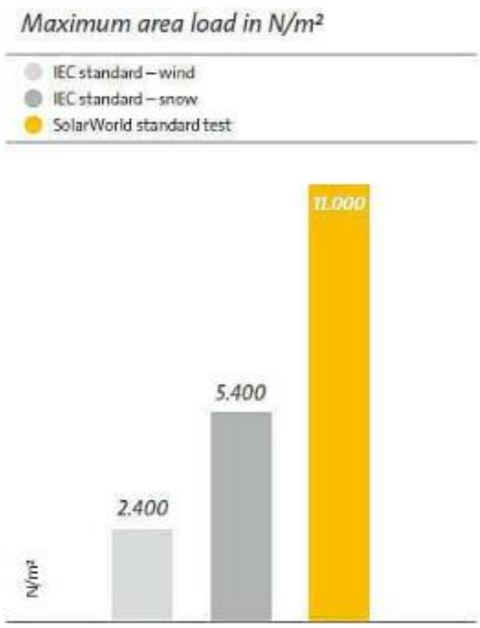

Figure 11. Pressure test for wind and snow [22]

1.5. PV PANELS MANAGING

PV panels delivery DC electricity with a fluctuant voltage and current depending on the irradiation they receive in each moment. It is known that irradiation can change every second due to climate conditions or other external factors like dust, clouds, leaves… In order to achieve constant values of current and voltage the PV panels have to be managed by inverters. The inverters follow the maximum power point (MPP) so that PV panels always give the maximum power they can, this system is named maximum power point track tracker (MPPT).

MPPT is needed because the MPP changes with the irradiation, temperature and the panel degradation so MPPT allows us to follow the MPP automatically just programing the inverters [13].

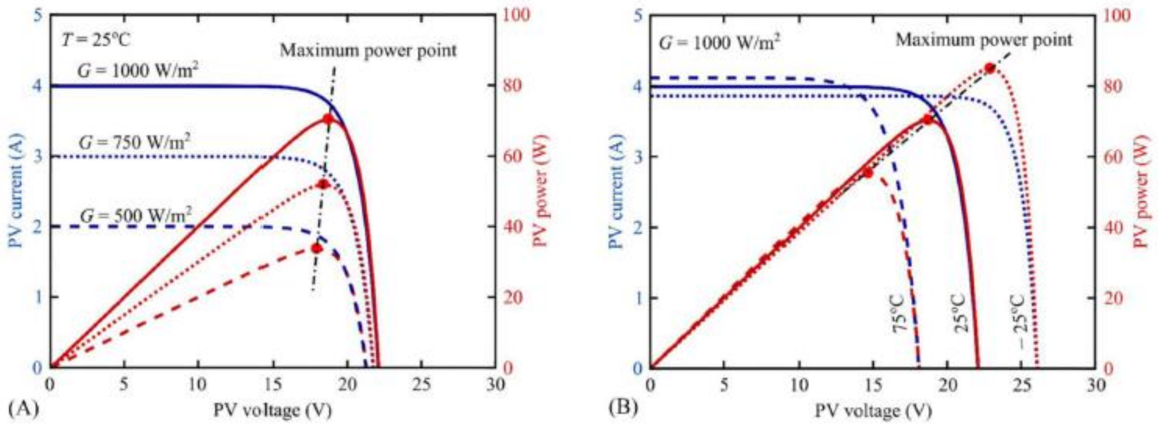

Figure 12. these graphs show the relation between how the point of maximum power (MMP) change regarding V-I curve variability [13]

Inverters are also capable to turn DC current into AC current and there are several mounting combinations to achieve the PV panels managing, the combination used in each situation depends on factors like the installation power, the performance or the budget.

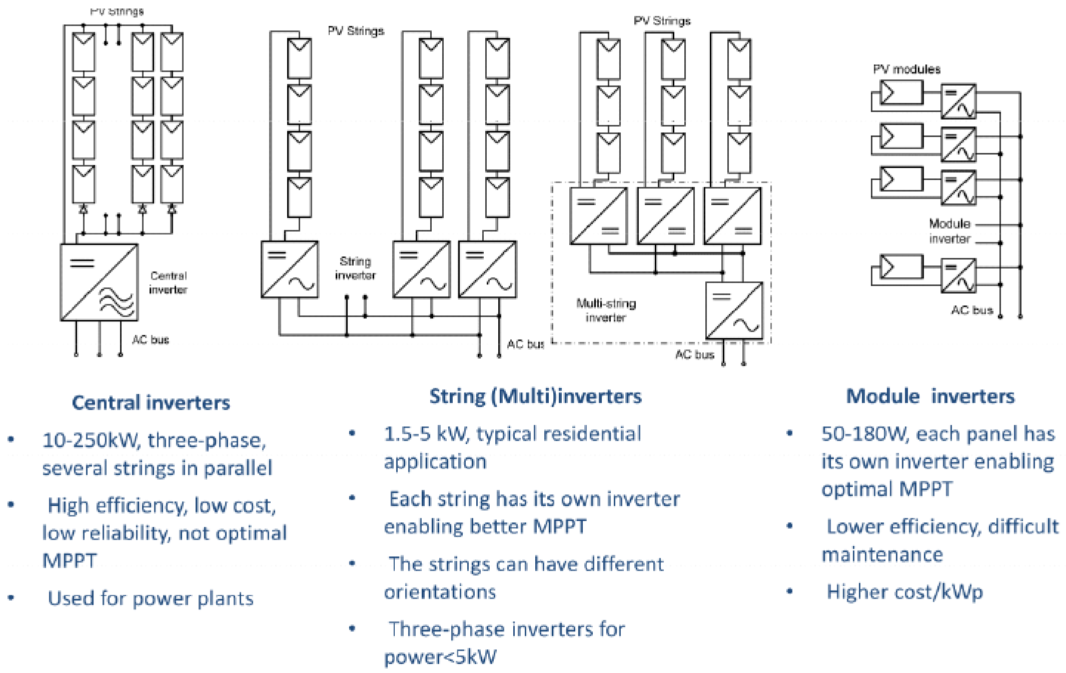

Figure 13.Different combination assemblymen and some of theirs features[13]

1.6. NEW TECHNOLOGIES AND DEVELOPMENT

Everything around PV panel technology is nowadays in constant development. Next sections show interesting technologies that make the PV panels more interesting.

1.6.1. Panels' orientation

The best way to achieve the maximum efficiency of the panel is keeping the PV panel surface perpendicular to the sun to receive the maximum direct normal irradiance (DNI), to reach this it is necessary to integrate a solar tracker system which needs a complex system with sensors, motors and mobile supports, although this system increases the panel performance it is hardly used because it has too much inconvenient, especially in big power plants: it has a bigger initial investment than fix support system, it needs more maintenance that also means an expensive maintenance and makes the power plant less reliability than the fixed one.

Due to the explained above nowadays the PV panels are placed in fixed way after an exhaustive study in search of the best fixed orientation towards the sun

1.6.2. Bifacial cells

Bifacial cells consist in cells capable to make a simultaneous conversion of the light that illuminates them from the front side as well as the from the back side into electricity, on this way the solar cell take advantage of albedo and diffuse irradiation as much as possible. Bifacial cells are usually made with monocrystalline silicon because it is more efficiency than monocrystalline silicon [23]. The encapsulation method used in these kinds of PV panels is very important and makes a huge difference in the performance.

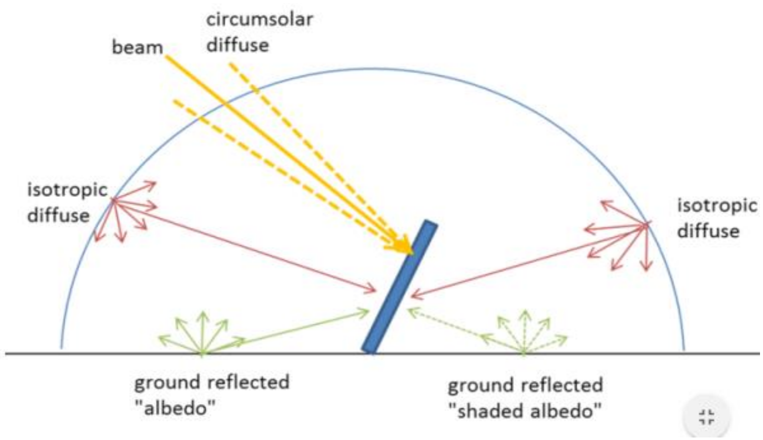

Figure 14. Irradiation that bifacial PV panel receives [24]

1.6.3. New encapsulating methods (TPO)

Copolymer EVA is the most popular encapsulation method and has been used in PV industry for more than twenty years. Over this long period of time, the EVA durability has been improved tremendously but the need to reduce the cost of PV modules opens the market for new encapsulation materials.

Thermoplastic polyolefin elastomer (TPO) is a blend polymer that has been used in automobile and building industry in the past and nowadays. TPO is an interesting candidate for PV encapsulation because of its low price. The material has a high electrical resistivity, it does not degrade under acetic acid formation and is resistant to hydrolysis although the water permeation of TPO is significantly higher than EVA [18].

1.6.4. BIPV and BAPV

These concepts are almost the same. The difference is that the word BIPV means "Building-integrated photovoltaics" and it refers replacing conventional building materials form building parts that wraps the building such as the roof, skylights or facades while BAPV means "building-applied photovoltaics" and it refers to photovoltaic systems that are integrated on the building after the construction is already finished [25].

These concepts are not something new. PV applications on buildings began appearing in the 1970s. Aluminium-framed photovoltaic modules were connected to, or mounted on buildings that were usually in remote areas without access to an electric power grid. In the 1990s BIPV construction products specially designed to be integrated into a building envelope became commercially available [26].

The advantage of the incorporation of photovoltaic systems in building design is that the increasing of costs can be compensated by the reduction of the expense in the construction materials and the saving in the assembly that is used to construct the part of the building that modules replace. These advantages allow to the PV applications on buildings (BIPV and BAPV) to be one of the segments of the photovoltaic industry that increases more rapidly.

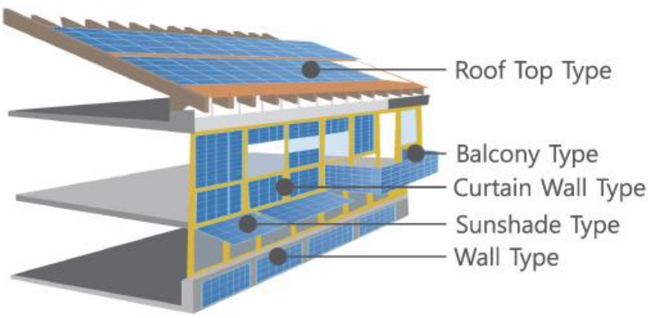

Figure 15. Example of BIPV [25]

CHAPTER 2. STAGE

This project is based on the study of four different PV panel technologies also placed in 5 different solar conditions. The place is assigned in a useful way in order to be able to establish a relation that shows which PV panel is more suitable and which solar condition is more efficient. The whole system function is watched by a monitoring system that collects and save all the information about factors such as temperature, wind, humidity and irradiance which are measured from several kinds of sensors. In this chapter it is written about all the components and devices that are needed to make a suitable tracking of the PV panel features as well as the weather and other conditions that must be considered.

2.1. PV PANELS PLACEMENTS

The PV panels are placed on the second floor terrace of the building TR 14 (Gaia building) together with other conventional panels that were placed 2 years ago and feed the building with energy.

Panels were assembled by the panel manufacturer following the scheme given by us:

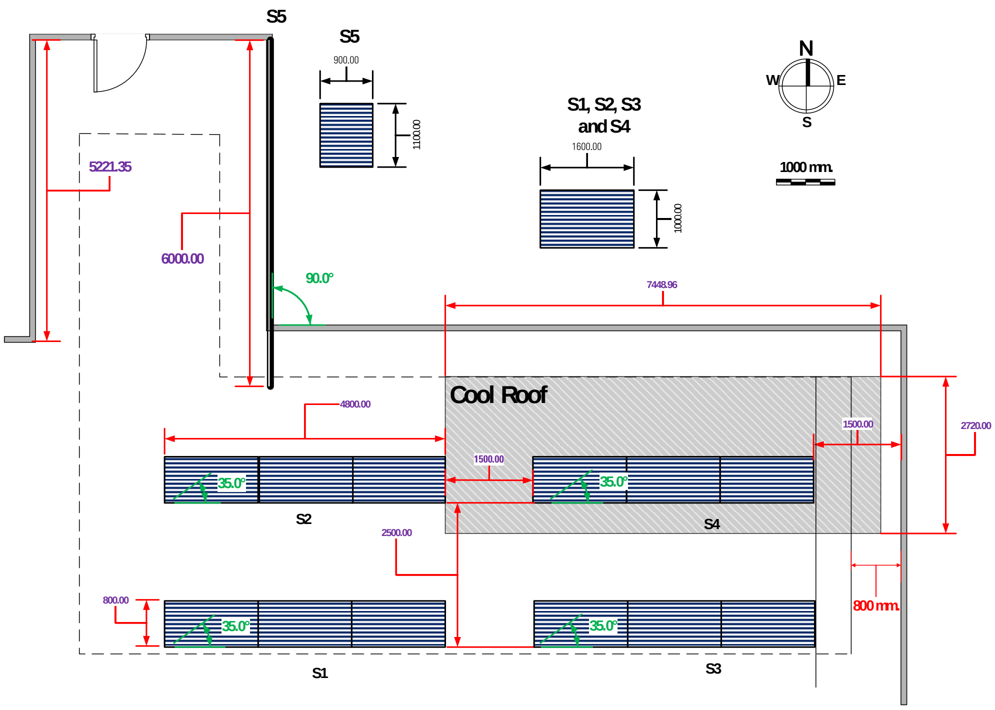

Figure 16. Placement dimensions

The placement properties of each panel are summarized in the next table:

	S1	S2	S3	S4	S5
Number of modules	3	3	3	3	6*
orientation	south	south	south	south	Est-west
Inclination (°)	35	35	35	35	90
Floor surface	cement	cement	cement	Special paint**	-

Figure 17. Location properties.

**there are six modules because these modules are smaller than the others panels, 6 modules of S5 are as big as 3 modules of the other panels.*

***The difference between S1 and S4 panels is that the floor under the panel is painted with a special paint to achieve reject the irradiance towards the back-sheet panel.*

Figure 18. This picture shows roof before their assembly. The S5 panels are situated in the bridge that connects the terrace with the indoor

Figure 19. Panels already located in its place

Because of in each position is placed more than one PV panel, it is interesting to be able to differentiate every single PV panel from each other. For that reason each PV panel has been named with its owner reference and single position.

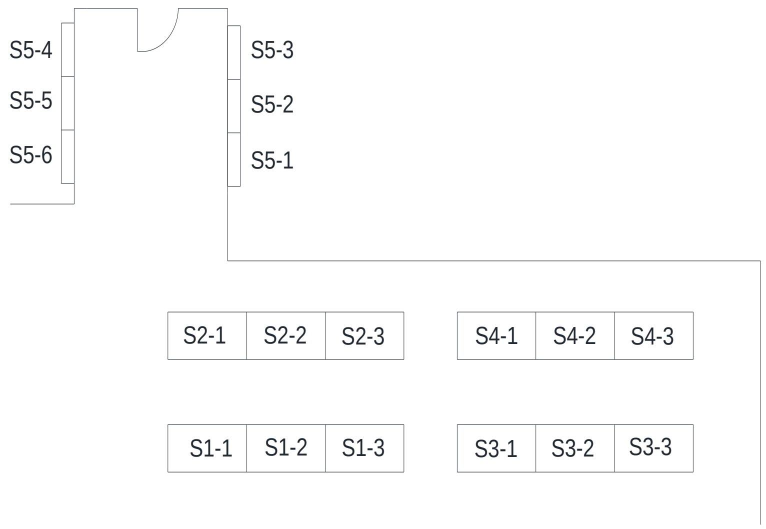

Figure 20. Established position of each panel

The panel references are:

Location	Reference
S1-1	190219AKW6B33011
S1-2	190219AKW6B33009
S1-3	190219AKW6B33010
S2-1*	200219AKW6B33020
S2-2	190219AKW6B33022
S2-3	190219AKW6B33021
S3-1	190219AKW6B33015
S3-2	190219AKW6B33017
S3-3	190219AKW6B33016
S4-1	190219AKW6B33014
S4-2	190219AKW6B33013
S4-3	190219AKW6B33001
S5-1	190219AKW6B33004
S5-2	190219AKW6B33008
S5-3	190219AKW6B33003
S5-4	190219AKW6B33005
S5-5	190219AKW6B33002
S5-6	190219AKW6B33007

Figure 21. PV panel references.

**the first panel was 190219AKW6B3W023 but it was changed due manufactured problems.*

2.2. PV PANEL FEATURES

As we have already seen in the previous point the panels are grouped in 5 different groups and these have a different name depending on where is located each PV panel in despite of there are just four types of panels. The names established are S1, S2, S3, S4 and S5. The general properties of them are:

	S1 and S4	S2	S3	S5
structure of the module	Glass-Glass	Glass-Black sheet (framed)	Glass-Glass	Glass-Glass
Cell technology	Bifacial	Mono cell	Bifacial	Bifacial
Cell dimension [mm]	156x156	156x156	156x156	156x156
Number of cells	60	60	60	30
Encapsulated method	EVA	EVA	TPO	EVA
Weight [Kg]	27	15	27	15

Figure 22. Structural properties

2.2.1. Modules electrical data

It's compulsory to know the panel features. The maker gave information about the cell features and also an external company made flash tests that helped to calculate estimated features. Then each panel feature was calculated from these properties obtaining theoretical and estimated features. Eventually the features used are the estimated because they are based in tests.

	Cell features	60 cells module theoretical features	60 cells module estimated features
Efficiency [%]	19.6	19.6	17.2
Pmax [W]	4.683	280.98	233
Voc [V]	0.642	38.52	37.557
Isc [A]	9.394	9.394	8.4546
Vmp [V]	0.534	32.04	31.239
Imp [A]	8.77	8.77	7.4545

Figure 23. Cell features

	S1	S2	S3	S4	S5
Pmax [W]	1012	843	1012	1180	708
Voc [V]	116	116	116	116	116
Isc [A]	11.3	9.4	11.3	13.2	7.9
Vmp [V]	96	96	96	96	96
Imp [A]	10.5	8.8	10.5	12.3	7.4

Figure 24. Total theoretical features

	S1	S2	S3	S4	S5
Pmax [W]	768	699	768	866	768
Voc [V]	113	113	113	113	113
Isc [A]	9.3	8.5	9.3	10.5	9.3
Vmp [V]	94	94	94	94	94
Imp [A]	8.2	7.5	8.2	9.2	8.2

Figure 25. Total estimated features

2.2.2. PV panels characterization

As it is already known the purpose of this project is take conclusions from a system constituted by PV panels prototypes, so they are that main components to take care of and know about their properties and features.

It must be done a testing to know which are the PV panel properties as well as check their well function. The most common test done over the PV panels and the one that give more information about the PV panels state is the PV panel characterization through the V-I curve as it has been reported in 1.4.2 section of this project.

Figure 26. Solar I-Ve by HT instruments

To obtain V-I curves it was bought a V-I tracker made by HT instruments: the "Solar I-Ve". This device lets know the V-I curve in the fastest and the most reliable way. Using the "Solar I-Ve" is easy, the first think needed is to set the PV panel features into the device through the buttons and the display (considering that bifacial panels are very capacitive this is needed to be set in the device, in other way the V-I curves will be not done due the current ripple). Once the PV panels features are set is possible to do the connection with the PV panel to check and obtain the curve just pressing a button and wait.

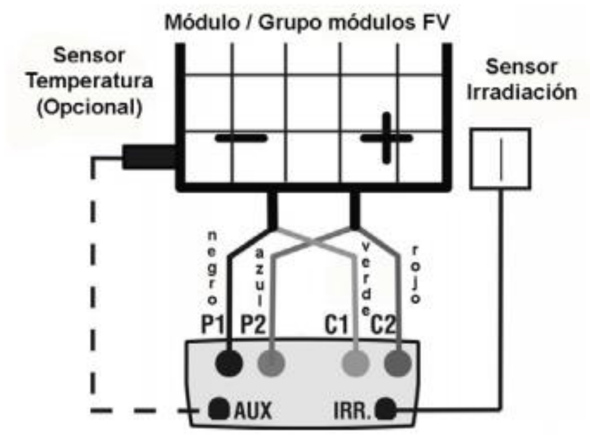

Figure 27. Connection scheme

The first results were not satisfactory and it was done a tracing during several month, the I-V curve was done again each month from march to September including a test with the PV panels backside covered avoiding the possibility of mistakes in tests due the specific bifacial cells features. The results were in all cases non-satisfactory and similar between them. The collected data was plotted using Matlab to show the results in a clear way.

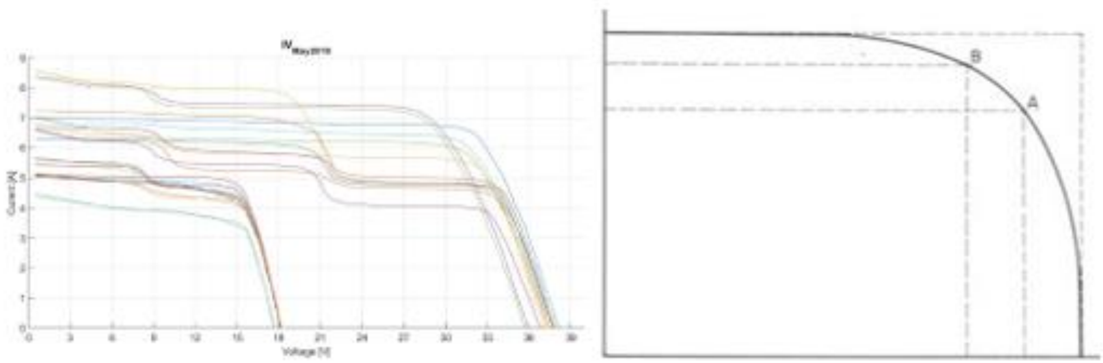

Figure 28. V-I curves from May (left) and typical curve V-I (right)

In the previous figure is showed that the bifacial cells shape is not suitable. Instead of being a smooth and clear line that starts in the top and slowly decreases to the bottom like the curve on the right most of the curves has several tops and a non-well defined line. These shapes are inadmissible due the MPP plot follows the same shape and this make not possible to be follow it by the inverters.

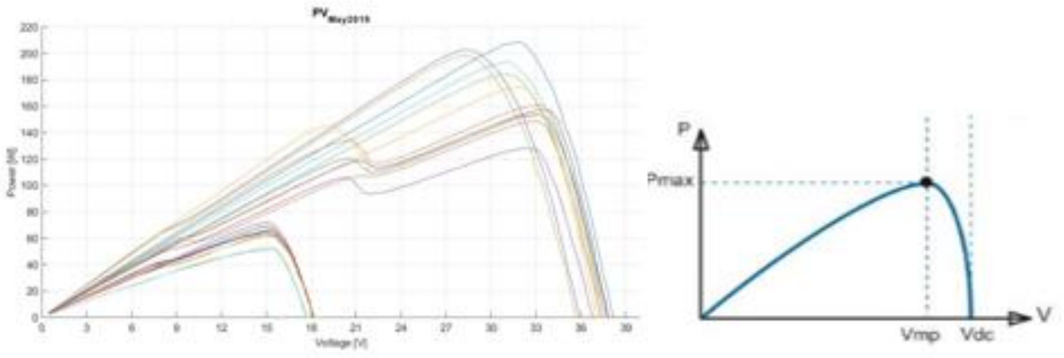

Figure 29. Obtained MPPT (left) and correct MPPT (right)

2.2.3. Manufacturer problems and hot spots

The PV panels were placed and started up on June, during that period they were working and some months after appeared signs of malfunction and degradation. In some cases the encapsulation looked broken letting the water and dust go into the cells and in other cells their colour looked more matt and dark than the others.

Figure 30. The most critical and visible damage

The V-I curves and cells seemed to indicate that PV panels were made in a bad way and some cells instead of producing energy were making a hot spot. The last test was checking the PV panels cells through a visual thermometer made by fluke (model VT04).

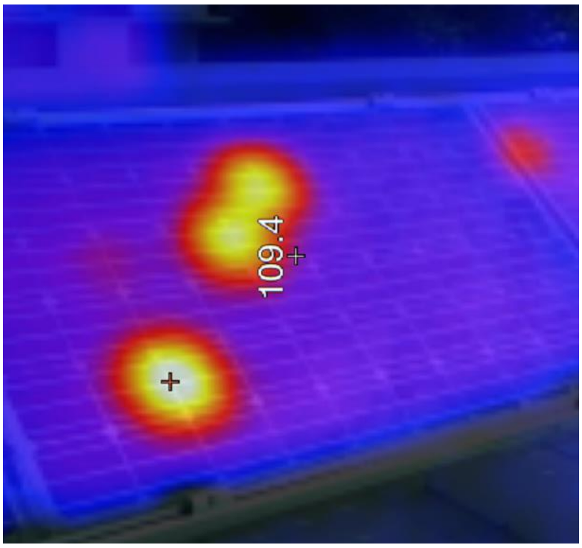

Figure 31. Visible hot spots in a PV panel

The previous figure show a picture from PV panel from the system, all of them had several spots whit some of these spots reaching temperatures about 100ºC.

2.2.4. Conclusion

The tests conclusion previously explained was that the PV panels were in bad condition and probably they were made in a wrong way. These issues were a big problem to the research due the whole system were not well working cause the PV panels.

After doing the report and sent it to the PV panels responsible of the final conclusion was that the PV panels had to be replaced like it is explained in the chapter 3 from this report.

2.3. SENSORS

In order to manage the PV panels and being able to study and surveillance the whole system, it is needed several sensors connected with a monitoring system. Here it is written about all the sensors features as well as their checking before the connection to verify their well working.

Figure 32. Weather outdoor cabinet solar irradiance, wind, humidity and ambient temperature measurement

2.3.1 Solar Irradiance

The irradiance is the PV panel source and because its measurement is the main parameter we have to take measurement. As it has already seen in the introduction of this project there are basically three types of irradiances and due to that is needed several devices in order to keep under surveillance all of them.

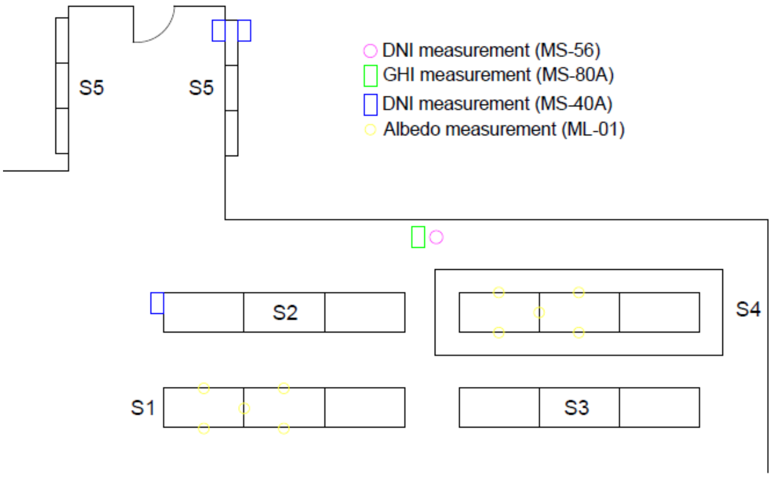

Figure 33. Irradiance sensor plan

Previous figure represents the sensors situations to gather the measurements. We can differentiate two groups:

- weather irradiance measurement: Two sensors are designated for the weather irradiance measurement, the first of them (MS-56) recollect the direct normal irradiance (DNI) data and the other one recollects the global horizontal irradiance (GHI), these two irradiance give us the main information about the irradiance that in each time we can take advantage.

- PV panel surface irradiation: all the other sensors are used to measure the irradiance that the PV panels are receiving in their surface, due to these sensors are located in horizontal way with the PV panels surface so we need two sensors to measure the radiation received on S5 surfaces (east and west) and another one in the same inclination as S1, S2, S3 and S4 that is located on S2 frame. We can't forget that the panels are bifacial and we must also take measurement of the irradiation from both surfaces so to take measurement of the back sides from S1, S2, S3 and S4 it is used albedo sensors, ten of them: 5 used to measure the irradiation that grey floor reject and 5 more to measure the irradiation rejected by white floor, all of them placed in a strategic way.

In the following sections it is explained the irradiances measure and the sensors used.

2.3.1. Direct normal irradiance, DNI

In order to control direct irradiances it is necessary a device that tracks the sun along the day to take the irradiance measure always in the correct angle. The used device is STR-21G and was already mounted and fixed on the terrace. It is only needed a single measure of direct irradiation because it is the same value at any point we take measure.

Figure 34. Pyrometer assembled in its support

Commercial Name	STR-21G
Manufacturer	EKO instruments
Motor	Stepping motor
Pointing accuracy	<0.01°
Resolution	0.009°
Tracking accuracy	0.01°
GPS accuracy	Horizontal Position: Below 15m (2drms). GPS Positioning
Sun sensor field of view	±15°
Temperature Range	-40…+50°C
IP Class	IP65
Communication	RS-232C, 9600bps, 8N1
Power requirement	100-240VAC, 50/60Hz, 20W
	24V(21 ~ 32VDC), 20W
Fuse	2A (φ5x20mm) for AC
	1.6A Fast Acting (φ5x20mm) for DC
weight	14.5 kg

Figure 35. Tracking system features

This pyrheliometer is sensitive to solar irradiance in the spectral range from 200 – 4000nm and works under the most extreme conditions in a temperature range from -40°C-80°C. The pyrheliometer is assembled in the tracking system support.

Commercial Name	MS-56
Manufacturer	EKO instruments
ISO 9060:1990	First Class
Output	Analog (mV)
Response time 95%	< 1 Sec.
Zero off-set a) 200W/m²	0 W/m²
Zero off-set b) 5K/hr	< 1 W/m²
Complete zero off-set c)	< 1 W/m²
Non-stability change/1 year	< 0.5 %
Non-linearity at 1000W/m²	< 0.5 %
Temperature response -20°C to 50°C	< 0.5 %
Tilt response at 1000W/m²	< 0.2 %
Sensitivity	Approx. 10 μV/W/m²
Impedance	Approx. 5000 Ω
Operating temperature range	-40…+80 °C
Irradiance range	0 - 4000 W/m²
Wavelength range	200 - 4000 nm
Ingress protection	IP 67
Cable length	10 m

Figure 36. Pyrheliometer features

The MS-56 pyrheliometer give mV signal between 4mV and 20mV, this signal is not suitable because the small voltage can be distorted by external factors like currents that cross other cables. To avoid this, the voltage signal is converted into current signal through a signal converter.

This pyrheliometer also has an internal temperature sensor to know its temperature and starting up the internal heat and avoid its lent become tarnished or frozen. Because of the country that is the pyrometer placed the temperature are not low, this device is not needed and is not used.

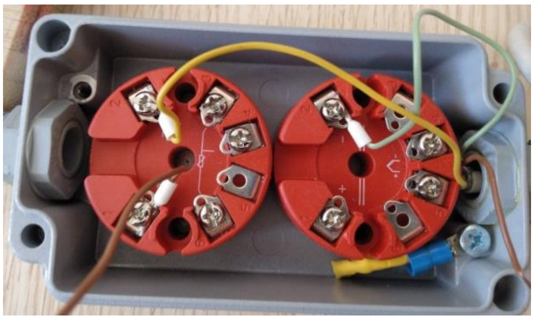

Figure 37. Converter inside, the left converter is not used (intended to internal temperature sensor)

This converter was to be checked before the placement in the laboratory but the handbook was not available because this converter model is old and there is no information about it on the brand website.

Commercial Name	MS converter
Manufacturer	EKO instruments
Output range	4…20mA

Figure 38. Known features of the converter

Before asking to several researchers of the building it was found a scheme about its connection so it was checked in the laboratory following the scheme given. The converter for the temperature signal was not checked because it is not necessary.

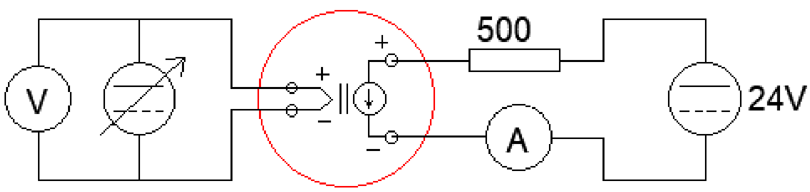

Figure 39. Checking scheme

In order to know the conversion linearity it had compared output values with input values:

Input (mV)	Output (mA)
0	3.88
5	9
11	14
14.5	18
16	20

Figure 40. Taken values

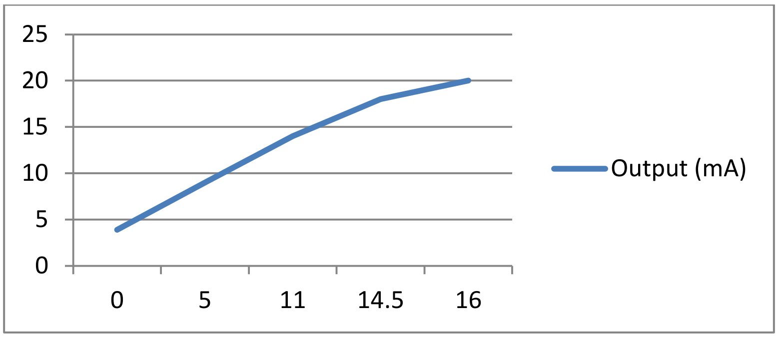

Figure 41. Converter linearity

The values taken are an approximation because of the few precision of the current sources of the laboratory but they are useful to know the linearity.

2.3.2. Global horizontal irradiance (GHI)

As is has been seen in the chapter 1, the global horizontal irradiance (GHI) has a particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI).

Due the importance of this measure it is used a suitable sensor with better features than the other irradiance sensors (except DNI sensor its commercial name is MS-80A). This sensor is placed on the bottom of the tracker system (STR-21G) close the MS-56 sensor through a specific support made by the same sensor maker.

Commercial Name	MS-80A
Manufacturer	EKO instruments
Output Digital	Digital 4-20mA
Response time	< 1.5 Sec
Non-linearity at 1000W/m²	+/- 0.2 %
Temperature response	+/- 0.5 %
Operating temperature range	-40 - 80 °C
Irradiance range	0 - 4000 W/m²
Wavelength rang	285 - 3000 nm
Power supply	12 - 24 VDC
Power consumption	0.08 - 0.5 W
Ingress protection	IP 67

Figure 42. MS-80A main features

Figure 43. MS-80A Sensor without the external protection

2.3.3. Diffuse horizontal irradiance (DHI)

In order to take DHI measures it is needed to install another pyrheliometer as the used for taking GHI measures on the STR-21G support and install a “shadow ball” that prevent DHI go into the sensor, in this way this new sensor only takes measures of the DHI.

Figure 44. STR-21G equipped with all the devices to measure DNI, GHI and DHI

2.3.4. Inclined solar irradiance

It is taken measure of the radiation that reaches the panels placing the same sensor model used for the GHI but in this case fixed with the same inclination that the PV panels. Because of this radiation is not as important as the GHI, it is used a lower model: MS-40A. It is needed three of them: one for the panels that are faced to the south and two used for the panels faced to the west and east.

Figure 45. MS-40A fixed

Commercial Name	MS-40A
Manufacturer	EKO instruments
Output Digital	Digital 4-20mA
Temperature response	+/- 3 %
Operating temperature range	-40 - 80 °C
Irradiance range	0 - 2000 W/m²
Wavelength rang	285 - 3000 nm
Power supply	12 - 24 VDC
Power consumption	0.08 - 0.5 W
Ingress protection	IP 67

Figure 46. MS-40 main features

The output is given in mA signal so it is not needed a converter to condition the signal.

MS-40A sensors were not provided by suitable supports that match with the PV panels frames and it was needed to design and made specific supports for them. After taking measurements and studying the position it was made a support design, then were made of polycarbonate through laser cut. The supports consist in two parts:

- The first part fixes the sensor on it and is designed to be able to be put on the frame through the second component. The thickness was stablished trough the plastic sheet used: 5mm. it was made three of them.

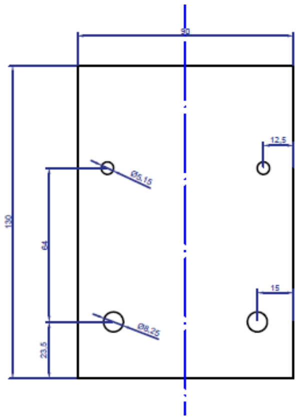

Figure 47. MS-40S first part support scheme

- The second part was designed to be introduced inside the PV panel frame in order to be able to screw the bolt preventing the nut from turning. It was made sawing an iron piece, drilling it and soldering a nut. Last step was painting the piece. It was made 6 of them.

Figure 48. Fixation scheme (left) before and after painting (right)

2.3.5. Solar irradiance in PV modules backside

We must know how much irradiance is receiving the PV panel back. This irradiance is the albedo irradiance and is measured be a specific sensor: ML-01.

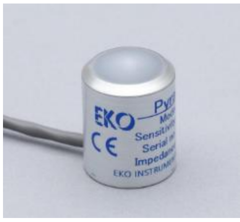

Figure 49. ML-01 Sensor

As it has been seen in the section 2.1 “PV Panels placements” a prototype is placed above a special floor that reflects more albedo than normal floor. Due to knowing the albedo irradiance is important to reach based conclusions from scientific data. Next figure shows the strategy to fix them. There are placed 10 albedo sensors. Five placed above high reflecting albedo floor (S4) and other five above low reflecting albedo floor (S1).

Figure 50. ML-01 fixed on PV panels frame

Commercial Name	ML-01
Manufacturer	EKO instruments
Output Digital	Analog (mV)
Response time	< 1 ms
Sensitivity	Approx. 50 µV/W/m²
Operating temperature range	-30 - 70 °C
Irradiance range	0 - 2000 W/m²
Wavelength rang	400 - 1100 nm

Figure 51. ML-01 features

The output signal is given in mV and it is needed to be converted, this job is made by NI9214 component and it is integrated within the monitoring system, it is possible to read about the monitoring system in its own section inside this project.

ML-01 sensors are not provided by suitable supports to be matched with the PV panels frames and it has been needed to design and made specific supports for them. After taking measurements and studying the position it was made a support design, then it were made of polycarbonate through laser cut. The supports consist in two parts:

- The first part fixes the sensor on it and is designed to be able to be put on the frame through the second component. The thickness was stablished trough the plastic sheet used: 5mm. It has been made ten of them.

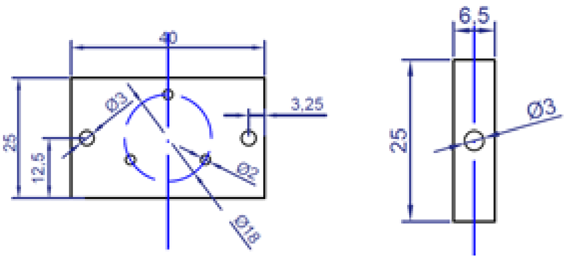

Figure 52. ML-01 supports

- Next part has been made to have space enough between the main support and the panel frame surface because the sensor is fixed through three bolts ant their heat has to fit in that gap. It is an easy design and it was made twenty of them. This part was fixed by a drop of glue to the main support just before to assembly the whole support on the panel frame by two pair of bolts.

Figure 53. Supports just after cutting (left) and before to be assembled with the sensor (right)

For the assembly on the PV panel frame it was required to do holes on the surface coinciding with the ones on the support and in some locations it was made another extra support to do a suitable fixing avoiding disturbing the panel function.

Next section shows the comparison between the signal sensors to know if there are some differences in each output sensor due the different range of sensitive existing between each one. It has been named each ML-01 sensor with a specific name according to the owner reference to ease correcting the differences through the software. The sensors are named and placed in this way:

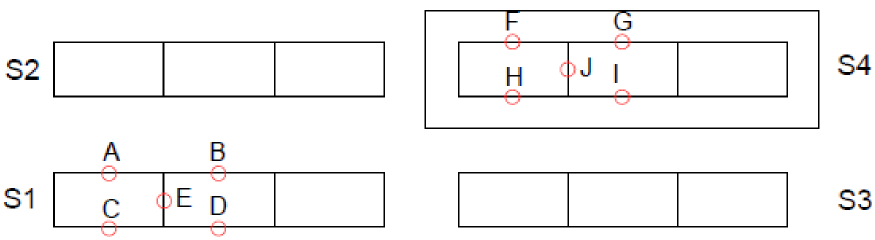

Figure 54. ML-01 sensor plan

Place	Name	Additional information
A	ML-745	Normal albedo
B	ML-741	
C	ML-743	
D	ML-813	
E	ML-742	
F	ML-811	High albedo
G	ML-744	
H	ML-814	
I	ML-812	
J	ML-740	

Figure 55. ML sensor name, according to figure 54

2.3.6. Irradiance sensors comparison

Before the final fixation of the pyrometers they were tested to characterize the differences between sensor signals. Otherwise if there are differences in the final measurements, it could be doubts about the error introduced by the sensor.

The way to do this test is taking measurements of every radiation sensors in the same position for at least one day to confirm that they show the same values.

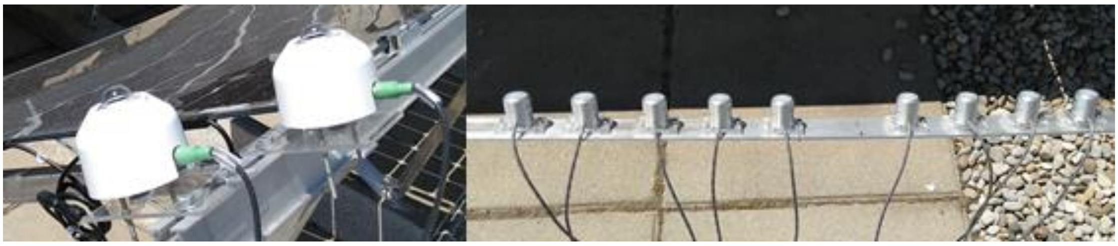

Figure 56. Sensors in the comparison process

After several recollected data during different days it was taken conclusions about inputs difference. It was put a results on an excel file, then it was programed the excel document to show the maximum relative difference between inputs from each time that it was recollected. Down these lines is showed data from different day times from each group of sensor. The difference is calculated taking the minimum row value as a reference and showing the relative difference in %.

- For ML-01 sensors:

Time of the day	E_ML740	E_ML741	E_ML742	E_ML743	E_ML744	E_ML745	E_ML811	E_ML812	E_ML813	E_ML814	Max	Min	difference (%)
31/08/2015 11:18	93.6	99.1	97.6	99.7	88.9	100.5	93.8	97.8	94.6	100.1	100.5	88.9	13.0
31/08/2015 11:18	93.2	98.7	97.0	99.0	88.5	99.8	93.2	97.3	94.0	99.6	99.8	88.5	12.8
31/08/2015 12:18	34.7	37.3	36.4	36.8	32.7	37.7	35.7	37.4	34.4	37.7	37.7	32.7	15.4
31/08/2015 12:18	34.8	37.3	36.3	36.9	32.7	37.7	35.6	37.4	34.4	37.7	37.7	32.7	15.5
31/08/2015 13:27	73.8	75.6	73.4	73.7	71.1	75.7	73.3	77.9	70.1	77.4	77.9	70.1	11.1
31/08/2015 13:28	77.3	78.8	76.3	76.7	74.3	79.0	76.5	81.5	73.1	80.6	81.5	73.1	11.5
31/08/2015 14:20	148.8	148.9	144.1	143.6	143.7	148.8	146.0	156.8	137.7	153.7	156.8	137.7	13.9
31/08/2015 14:20	149.2	149.3	144.6	143.9	144.1	149.3	146.5	157.3	138.1	154.2	157.3	138.1	13.9
31/08/2015 15:06	164.3	160.5	152.6	149.4	160.5	159.9	160.1	174.3	145.1	167.9	174.3	145.1	20.2
31/08/2015 15:06	159.3	156.8	148.9	146.0	157.0	156.5	156.1	170.2	142.0	162.9	170.2	142.0	19.8
31/08/2015 15:54	98.1	94.0	88.4	86.0	95.9	92.7	96.4	105.5	82.7	100.0	105.5	82.7	27.5
31/08/2015 15:55	81.9	79.3	75.1	73.6	79.7	78.7	81.3	88.5	70.1	84.2	88.5	70.1	26.3
31/08/2015 16:52	86.5	82.3	77.9	76.5	84.9	81.2	85.1	93.3	72.9	87.6	93.3	72.9	28.0
31/08/2015 16:52	86.5	82.3	77.9	76.5	85.0	81.4	85.2	93.4	72.9	87.7	93.4	72.9	28.2

Figure 57. Some recollected data from ML-01 sensors

- For MS-40A

Time of the day	E_MS40A	E_MS40A_East	E_MS40A_West	Max	Min	Retalive difference (%)
31/08/2015 12:18	123.8	117.2	119.4	123.800	117.200	5.631
31/08/2015 12:18	123.7	117.1	119.4	123.700	117.100	5.636
31/08/2015 13:27	367.5	357.6	357.8	367.500	357.600	2.768
31/08/2015 13:28	383.3	372.9	374.2	383.300	372.900	2.789
31/08/2015 14:20	755.7	742	738.4	755.700	738.400	2.343
31/08/2015 14:20	753.3	739.7	735.8	753.300	735.800	2.378
31/08/2015 15:06	751.8	731.8	751.7	751.800	731.800	2.733
31/08/2015 15:06	758	738	757.4	758.000	738.000	2.710
31/08/2015 15:54	422.4	410.2	415.6	422.400	410.200	2.974
31/08/2015 15:55	353.2	344	343.9	353.200	343.900	2.704
31/08/2015 16:52	362.1	347.5	349.5	362.100	347.500	4.201
31/08/2015 16:52	363	348.7	350.7	363.000	348.700	4.101

Figure 58. Example of data from MS-40A

We have recollected data from every irradiance sensors but we can only take conclusions about the sensitive differences just about those we are using more than one and indeed we have studied all the data recollected (in total data from nine sensors taken between august and September) and the result was in all cases similar to the tables showed in this project.

The final conclusion is that the relative difference obtained in the results for ML-01 sensors there are important differences to take into account, from my point of view is something to correct or keep in mind at the moment to take conclusions.

If we speak about the MS-40A sensor the relative difference obtained is not high enough to be a problem for us in the researching and it is not needed to take actions in order to solve the small differences observed in this study.

2.3.7. Anemometer

The wind speed is another atmospheric feature that it has to be measured. The anemometer turns the speed of the wind into electric signal by a reed contact activated by the effect of magnets. The activation frequency depends on the wind speed that spins the main shaft. Because of the signal is a pulsating frequency, it is needed to turn into mA signal. This sensor does not need maintenance.

Commercial Name	SVR-40
Manufacturer	DISIBEINT ELECTRONIC,S.L.
Wind speed range (m/s)	0.5-40
Accuracy (m/s)	±0.5
Range Signal Output (Hz)	0-100
Range temperature °C	-25 −+60
Weight (kg)	0.3
Ingress protection	IP54
Material	ABS

Figure 59. Wind speed features

Z111 is the converter name used and allows a frequency signal conversion, it provides mA or mV standard output signal. The input is programmable in a range from 1 MHz to 9,99 KHz. It's completely configurable through dip switches. A 3-way galvanic isolation among power supply, input, and output circuits assures the integrity of the data.

Figure 60. Converter used

Z111 was checked in the laboratory simulating the connection in the laboratory following the data sheets. The scheme done and tested in the laboratory was:

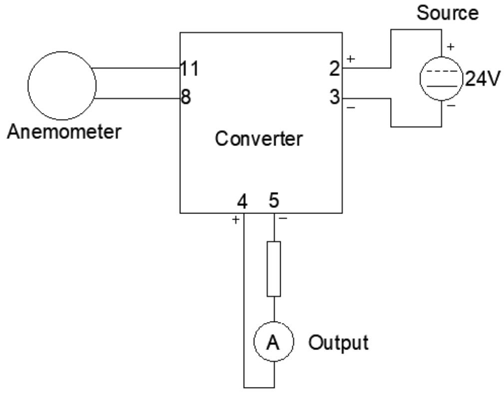

Figure 61. Test scheme

The converter has to be set from several selectors which are provided in order to select the correct range of signal output or input. After the setting and testing the result of the checking was satisfactory according with the outputs given by it.

Figure 62. Setting of the converter for our system features

Commercial Name	Z111
Manufacturer	SENECA
Power supply	10..40 Vdc / 19..28 Vac / 50-60 Hz
Input	Contact / reed; npn 2/3 wires; pnp 3 wires with 24 Vdc power; namur; photoelectric; hall effect sensor, variable reluctance, 24V; TTL Max frequency: 10 kHz
Output	Voltage: 4 scales: 0..1, 0..5, 0..10, 2..10 V Min load resistor: 2.000 Ω
	Current: 2 scales: 0/4..20 mA (active/passive) Max load resistor: 600 Ω

Figure 63. Anemometer features

We must extract the linear equation to turn the mA signal into m/s value to know how much wind the signal is. Intensity signal is not suitable to the study. It must be established the relation between the speed wind and converter signal:

Converter current range [mA]	4-20
Sensor speed range [m/s]	0-40
Relation speed/ current	lineal

Figure 64. Features for the relation speed/current

Knowing that the general equation for lineal relations is:

$$y = m \cdot x - b$$

And:

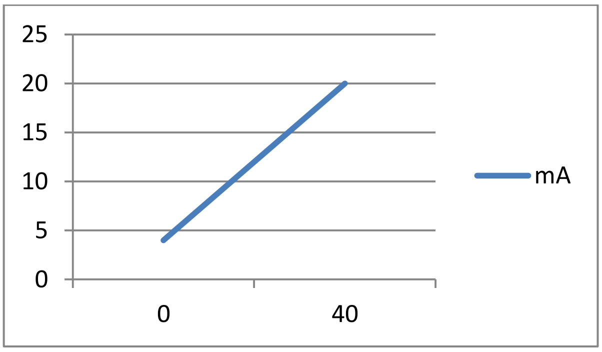

Figure 65. Signals relations according datasheet

We can find the value of *m*:

$$m = \frac{y_2 - y}{X_2 - X_1} = \frac{(20 - 4)}{40} = 0.4$$

And now *b*:

$$y = m \cdot x - b \rightarrow b = y - (m \cdot x) = 4 - (0 \cdot 0.4) = 4$$

Finally:

$$y = m \cdot x - b \rightarrow x = \frac{y - b}{m} \rightarrow x = \frac{y - 4}{0.4} \rightarrow \boldsymbol{x = 2.5y - 10}$$

Where *x* = wind speed [m/s] and *y* = current intensity [mA]

2.3.8. Atmospheric pressure sensor

Atmospheric pressure is another property to take data in order to study the system performance. This parameter is measured by ALD-U sensor that has been also tested before the placement.

Figure 66. Atmospheric pressure sensor

Commercial Name	ALD-U
Manufacturer	S+S REGELTECHNIK
Power supply	24V
Output signal	0-10 V
Current consumption	20mA
Type of pressure	Absolute pressure
medium	Air and other non-aggressive gases
Measuring range	850-1150mbar / 750-1250 mbar (selectable via DIP switches)
Max. pressure	2000 mbar
accuracy	±1.5% of final value at +20°C
Long-term stability	±0.5% of final value per year
Linearity	±0.5% of final value
Ambient pressure	-10…+50°C
Operating range	10…90% r.H.
Protection type	IP65

Figure 67. ALD-U features

In this case we do not need a converter due the sensor is able to give V signal instead of mV signal which is enough high to not be distorted by external factors.

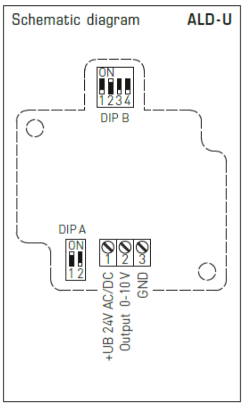

Figure 68. Schematic picture

This sensor has to be set by DIP switches placed in its inside to establish the measuring range and the measurement signal selection.

DIP		Set	Meaning
A [measuring range]	**1**	On	Range: 850-1150 mbar
	2	Off	
B[Measurement signal]	**3**	Off	Time interval: 0s
	4	Off	

Figure 69. DIP setting

Knowing the parameters being set then it was done the test in the laboratory connecting the following scheme:

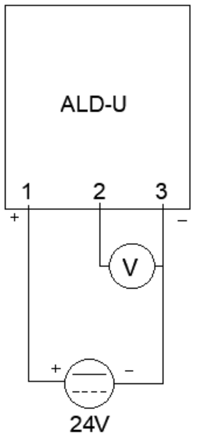

Figure 70. Test scheme

We must extract the linear equation to convert the V to pressure value to be able to see the pressure value in our system in mbar, a value of V is not important to us. We can establish the relation from the sensor and converter features:

Converter voltage range [V]	0-10
Sensor pressure range [mbar]	850-1150
Relation speed/ current	lineal

Figure 71. Features for the relation speed/current

Knowing that the general equation for lineal relations is:

$$y = m \cdot x - b$$

And the plot:

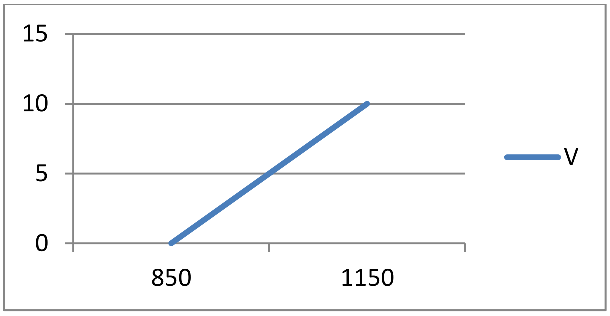

Figure 72. mbar/V relation

It is possible to find the *m* value:

$$m = \frac{y_2 - y}{X_2 - X_1} = \frac{(10-0)}{1150-850} = \frac{1}{30}$$

And now *b*:

$$y = m \cdot x - b \rightarrow b = y - (m \cdot x) = 0 - \left(\frac{1}{30} \cdot 850\right) = \frac{85}{3}$$

Finally:

$$y = m \cdot x - b \rightarrow x = \frac{y-b}{m} \rightarrow x = \frac{y - \frac{85}{3}}{\frac{1}{30}} \rightarrow x = 30 \cdot \left(y - \frac{85}{3}\right) \rightarrow \boldsymbol{x = 30y - 850}$$

Where *x* = Pressure [mbar] and *y* = Voltage [V]

2.3.9. Humidity and temperature

Figure 73. Humidity and temperature outside measurement sensor (KFTF-I)

The device used takes humidity and temperature measurement at the same time but it is not possible to read the temperature without connect the humidity sensor. That is the only thing to consider.

Commercial Name (Model)	KFTF-I
Manufacturer	S+S REGELTECHNIK
Power supply	15…36V
Output signal	4..20mA
Measuring range	multi-range switching with 4 switchable measuring ranges –35...+35 °C; –35...+75 °C; 0...+50 °C; 0...+80 °C (output corresponding to 0 -10 V or 4...20 mA)
Ambient temperature	operation – 30...+75 °C
Long-term stability	±1% of final value per year
Operating range	10…90% r.H.
Protection type	IP65

Figure 74. KFTF-I Features

This sensor output is given mA and it is not necessary to put a converter to condition the signal.

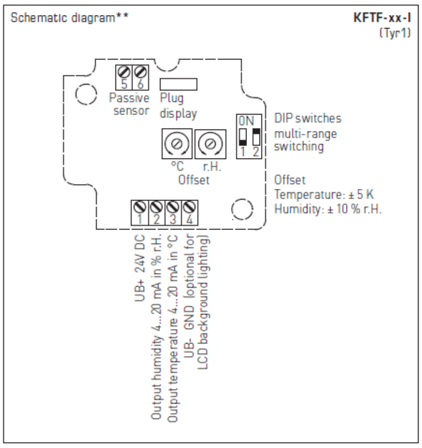

Figure 75. Schematic diagram

This sensor has to be set by DIP switches placed inside it to establish the measuring temperature range, the DIP setting was:

DIP 1	ON	Range of temperature: -35…+75 ºC
DIP 2	ON	

Figure 76. DIP setting

With this DIPs configuration the useful tables from the datasheet are:

Temperature table
MR: –35…+75 °C

°C	U_A in V	I_A in mA
-35	0.0	4.0
-30	0.5	4.7
-25	0.9	5.5
-20	1.4	6.2
-15	1.8	6.9
-10	2.3	7.6
-5	2.7	8.4
0	3.2	9.1
5	3.6	9.8
10	4.1	10.5
15	4.5	11.3
20	5.0	12.0
25	5.5	12.7
30	5.9	13.5
35	6.4	14.2
40	6.8	14.9
45	7.3	15.6
50	7.7	16.4
55	8.2	17.1
60	8.6	17.8
65	9.1	18.5
70	9.5	19.2
75	10.0	20.0

Humidity table
MR: 0…100 % r.H.

% r.H.	U_A in V	I_A in mA
0	0.0	4.0
5	0.5	4.8
10	1.0	5.6
15	1.5	6.4
20	2.0	7.2
25	2.5	8.0
30	3.0	8.8
35	3.5	9.6
40	4.0	10.4
45	4.5	11.2
50	5.0	12.0
55	5.5	12.8
60	6.0	13.6
65	6.5	14.4
70	7.0	15.2
75	7.5	16.0
80	8.0	16.8
85	8.5	17.6
90	9.0	18.4
95	9.5	19.2
100	10.0	20.0

Figure 77. Output for each temperature and humidity value

If the values are represented on a chart it is seen that the system is lineal:

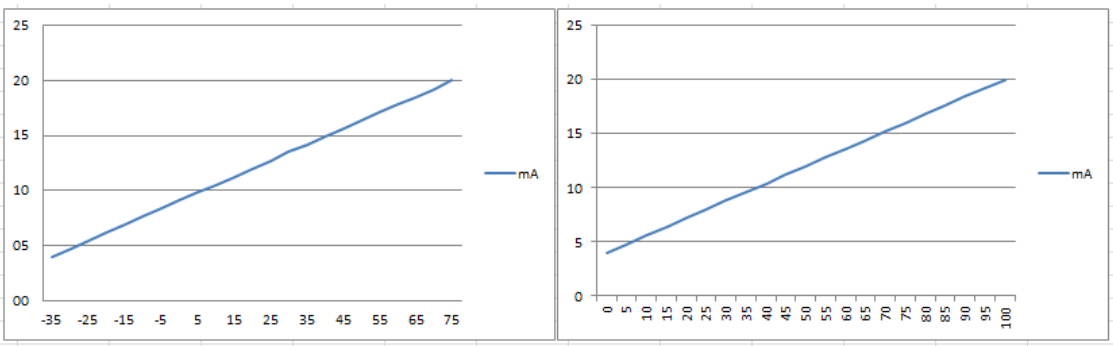

Figure 78. Temperature sensor output (left) and humidity sensor output (right)

It is possible to find the linear equation for each output, knowing that the general lineal equation is:

$$y = m \cdot x - b$$

- Temperature equation:

m value:

$$m = \frac{y_2 - y}{X_2 - X_1} = \frac{(20-4)}{75-(-35)} = \frac{8}{55}$$

B value:

$$y = m \cdot x - b \rightarrow b = y - (m \cdot x) = 4 - \left(\frac{8}{55} \cdot 0\right) = 4$$

Finally:

$$y = m \cdot x - b \rightarrow x = \frac{y-b}{m} \rightarrow x = \frac{y-4}{0.16} \rightarrow \boldsymbol{x = 6.875y - 62.5625}$$

Where *x* = Temperature [ºC] and *y* = Current [mA]

- Humidity equation:

m value:

$$m = \frac{y_2 - y}{X_2 - X_1} = \frac{(20-4)}{100-0} = 0.16$$

B value:

$$y = m \cdot x - b \rightarrow b = y - (m \cdot x) = 9.1 - (0.16 \cdot 0) = 9.1$$

Finally:

$$y = m \cdot x - b \rightarrow x = \frac{y-b}{m} \rightarrow x = \frac{y-9.1}{0.16} \rightarrow \boldsymbol{x = 6.25y - 56.875}$$

Where *x* = Humidity [%] and *y* = Current [mA]

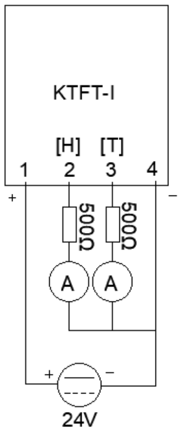

Figure 79. checking scheme

2.3.10. Temperature cells and floor: thermocouples

The PV panel temperature is an important parameter to be known because this value can change the V-I curve shape and also the MPP curve. Due to that fact is necessary to put several temperature sensors among PV panels.

Thermocouples are a suitable way to take temperature measurements of PV panels because commercial thermocouples are inexpensive, interchangeable, supplied with standard connectors and they can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self-powered and require no external source form of excitation.

Thermocouples are widely used in science and industry. The Applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. Thermocouples are also used in homes, offices and businesses as temperature sensors in thermostats, and also as flame sensors in safety devices for gas-powered appliances.

Figure 80. Thermocouple type K is the used in the project

They are composed by two different materials united by one side. When the union is heated or cooled a voltage appears in the union, this voltage is proportional to the temperature. Thermocouples are available in several metal combinations in order to be adapted to a several applications. The most common types are J, K, and T but exist other types like N, R, S, B, and E [27].

Commercial Name (Model)	847-9744
Manufacturer	RS PRO
Type	K
Insulation	Teflon® PFA insulated twin-twisted lead
length	10m
Temperature range	–75°C to +250°C
Main applications	for test & development applications
Output (mV)	-6.458..+54.886
sensitivity	41 µV/°C

Figure 81 Thermocouple features

It is needed a specific device to send the signal give it by them to the software, this component is the NI9214 from national instruments and it is a recollection data system component. There is a whole section to speak about this system in next sections but now it is important to say that NI9214 do a direct conversion between the output signal and the related temperature just setting the thermocouple parameters in the software.

Next point of this project it is seen the comparison between thermocouples sensors signal to know if there are some differences in each output sensor due the sensitivity range, they have been named by a specific name according to the owner reference, that way lets to correct the differences through the software. The sensors are named and placed according the next figure.

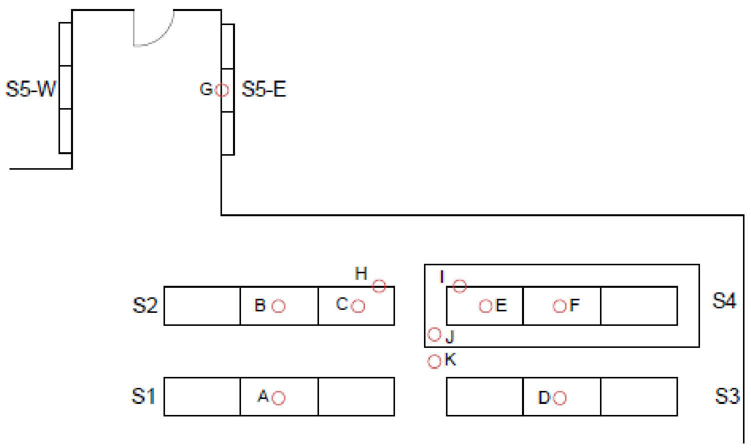

Figure 82. Thermocouple plan

Place	Measurement	Name
A	S1 temperature cell	TC_S1_CH7
B	S2 temperature cell	TC_S22_CH9
C	S2 temperature cell	TC_S21_CH2
D	S3 temperature cell	TC_S3_CH6
E	S4 temperature cell	TC_S41_CH1
F	S4 temperature cell	TC_S42_CH12
G	S5 temperature cell	TC_S5_CH8
H	Floor temperature in the shadow	TF_S2_CH5
I	Cool floor temperature in the shadow	TF_S4_CH3
J	Cool floor temperature	TF_HR_CH0
K	Floor temperature	TF_CH4

Figure 83. Sensor name, according to figure 82

2.3.11. Thermocouples sensor difference

Before the thermocouples final fixation they were tested in order to characterize the differences between sensor signals. Otherwise if there are differences in the final measurements, it could be doubts about the error introduced by the sensor.

The way to do this test is taking measurements of every radiation sensors in the same position for at least one day to confirm that they show the same values.

After several recollected data during different days it was taken conclusions about inputs difference. It was put a results on an excel file, then it was programed the excel document to show the maximum relative difference between inputs from each time that it was recollected. Down these lines is showed data from different day times from each group of sensor. The difference is calculated taking the minimum row value as a reference and showing the relative difference in %.

Time	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	Max	Min	Retalive difference (%)
6/19/2015 09:18:43.992	25.2	24.8	24.9	25.0	25.0	25.0	25.1	25.3	25.1	25.3	24.8	1.8
6/19/2015 09:18:45.033	25.2	24.8	24.9	25.0	25.0	25.0	25.1	25.3	25.1	25.3	24.8	1.7
6/19/2015 09:46:42.117	24.2	23.8	23.9	24.2	23.9	24.1	24.1	24.6	24.1	24.6	23.8	3.6
6/19/2015 09:46:43.158	24.2	23.8	23.8	24.2	23.9	24.2	24.1	24.7	24.1	24.7	23.8	3.6
6/19/2015 09:56:24.408	24.3	23.7	23.7	24.0	24.0	24.3	24.1	24.6	24.1	24.6	23.7	3.7
6/19/2015 09:56:25.450	24.3	23.7	23.8	24.0	23.9	24.3	24.1	24.6	24.1	24.6	23.7	3.6
6/26/2015 23:19:08.545	25.4	25.4	25.5	25.4	25.5	25.9	25.6	25.6	25.5	25.9	25.4	1.8
6/26/2015 23:19:09.587	25.4	25.4	25.6	25.4	25.5	25.9	25.6	25.6	25.5	25.9	25.4	1.8
6/27/2015 06:00:16.418	25.7	25.6	25.8	25.6	25.7	26.2	25.9	25.8	25.8	26.2	25.6	2.3
6/27/2015 06:00:24.144	25.7	25.6	25.8	25.6	25.8	26.2	25.9	25.8	25.8	26.2	25.6	2.1
6/27/2015 12:50:36.168	24.7	24.6	24.3	24.7	24.4	24.4	24.5	24.8	24.9	24.9	24.3	2.3
6/27/2015 12:50:37.210	24.7	24.6	24.3	24.7	24.4	24.4	24.5	24.8	24.9	24.9	24.3	2.3
6/19/2015 11:43:28.078	23.9	23.7	23.7	23.6	23.7	24.5	24.0	23.9	23.8	24.5	23.6	3.8
6/19/2015 11:43:29.119	23.9	23.7	23.7	23.6	23.7	24.5	24.0	24.0	23.8	24.5	23.6	3.8

Figure 84. Comparison results

It has been recollected data from all thermocouples and indeed it has been also studied all the data and the result was in all cases similar to the tables showed in this project.

The final conclusion is that the relative differences obtained are not big enough to be a problem in the researching and it is not needed to take actions in order to solve the small differences observed in this study.

2.3.12. AC Intensity

The AC current intensity measurement is one of the easiest parameters of the current to take data. The sensor that turn the current into a signal is based in a coil that is induced by the current that cross its inside, the coil give a voltage signal that depends on the current intensity in a direct way that cross the wire where the measurement is taken.

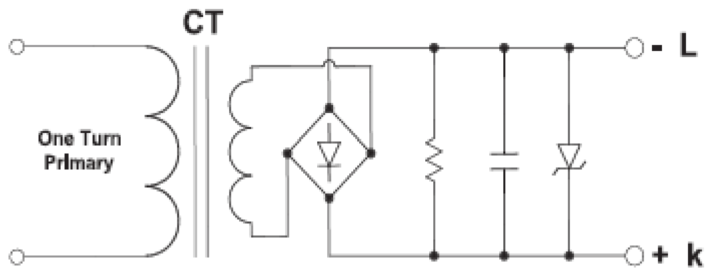

Figure 85. Schematic internal circuit

How it has been seen in last figure that the brown wire (the phase) is crossing the coil meanwhile this one send a signal through two bicoloured wires which are connected to the recollecting data system.

Figure 86. Current sensor working.

Categories	Current Transformers/Sensors
Reference	DCT-0010-010
Manufacturer/Brand	Magnelab
Series	DCT
Shape/Style	Split-Core
Input Rating (A)	10
Standard Output	5 V
Input Type	AC
Output Type	DC
Error (%)	2.0
Output Impedance (Ω)	8.5 KΩ
Power Type	Passive
# of Inputs	1
Weight (lbs)	0.25
Current or Voltage	Voltage

Figure 87. Main features of de current sensor

The signal is give it in V instead of mV, due to that fact it is not needed to process it.

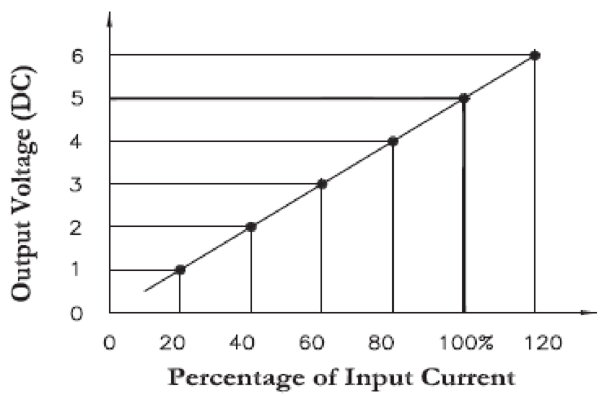

Figure 88. Relation between output and input

Looking at the datasheet it is found the relation between the output and the input, as it is shown in last figure the relation is lineal. It must be taken into account that 100% input make reference to a 10A according to the sensor range.

It must be extracted the linear equation to convert the input to be able to know the current value in the monitoring system. It is possible to establish the relation from the input and output values:

output range [V]	0-5
Input range [A]	0-10
Relation output/input	lineal

Figure 89. features for the relation output/input

Knowing the general lineal equation:

$$y = m \cdot x - b$$

m value:

$$m = \frac{y_2 - y}{X_2 - X_1} = \frac{(5-0)}{10-0} = 0.5$$

b value:

$$y = m \cdot x - b \rightarrow b = y - (m \cdot x) = 5 - (0.5 \cdot 10) = 0$$

Finally:

$$y = m \cdot x - b \rightarrow x = \frac{y-b}{m} \rightarrow x = \frac{y-0}{0.5} \rightarrow \boldsymbol{x = 2y}$$

Where *x* = AC Current [A] and *y* = output signal [V]

2.3.13. AC Voltage

To know the grid voltage it is used the Z-204-1, one of them per phase. This device made by Seneca needs set several configurations to make them functional and suitable to our system.

Figure 90. Z204-1 sensors placed and working in the system

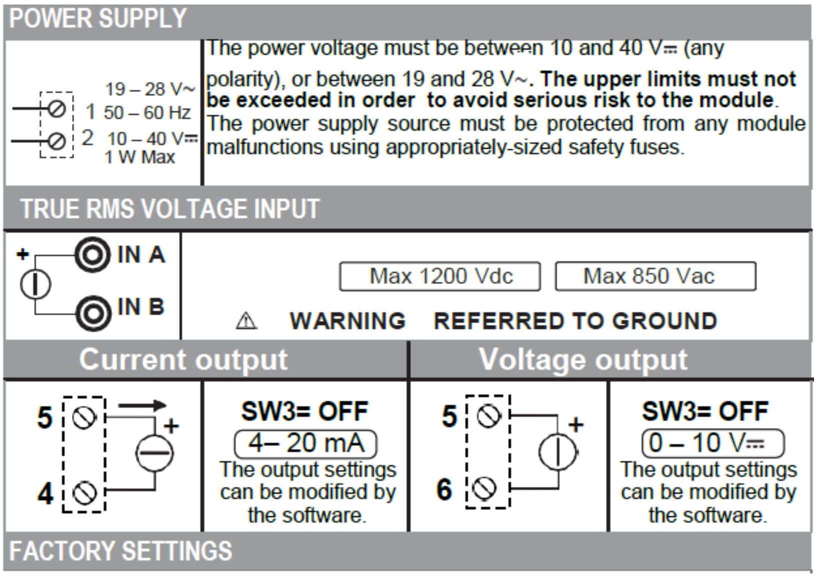

Figure 91. Connection information

GENERAL DATA	
Power supply	10..40 Vdc 19..28 Vac (50..60 Hz)
Insulation	4,000 Vac (input/output, input/power supply) 1,500 Vc (output/power supply)
Response time	For a step variation 1 s from 10 to 90 %
Precision class	0,5% input; 0,1% outputs.
Settings	Dip-switch (address, baud rate, line terminator, input range) EASY-SETUP (Plug&Play software)
Certifications	EC
Regulations	EN 61000-6-4, EN61000-6-2, EN61010-1
INPUT DATA	
Type	CONTINUOUS VOLTAGE: 0..1,200 Vdc; ALTERNATE VOLTAGE 0..850 Vac Input impudence: 800 KΩ Frequency: 30..300 Hz
OUTPUT DATA	
Type	CURRENT Range: 0..20 mA; max impudence: 500 Ω VOLTAGE Range: 0..10 V; Min impudence: 1 KΩ

Figure 92. Z204-1 main features

This sensor has also DIPs that have to be set depending on the application is going to be used. In this case it has been set the DIP as the following pictures and according the datasheets.

Figure 93. Z-204-1 backside

SW1								Meaning
1	2	3	4	5	6	7	8	Range: 0-600V
Not used						Off	On	
SW2								
1	2	3	4	5	6	7	8	Not used
Off	Off	Off	Off	Off	Off	Off	Off	
SW3								
1	2	3	4	5	6	7	8	Analog output (measurement to the terminals 4, 5, 6)
Off	-	-	-	-	-	-	-	

Figure 94. DIP set

In this particular case the device had to be configured through a computer and through apecific software downloaded from the maker website. The communication between the computer and the sensor is possible due a specific wire that is provided by Seneca but it was made one using components and facilities available in the laboratory. The output used is mA values that corresponds to the terminals 4 and 5.

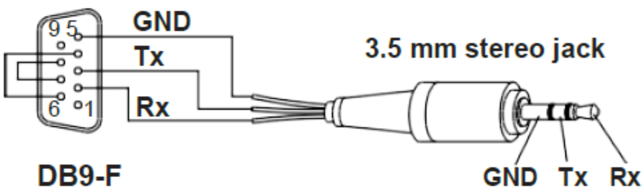

Figure 95. Wire needed according to the datasheet

Figure 96. Wire made it in the laboratory (left) and the program used and downloaded from Seneca website (right)

The sensor was checked in the laboratory as the other sensors with the particularity that variable alternate source of voltage is not available in the laboratory. It was only done the starting up and measurement of the grid voltage.

The result was:

Grid voltage (V)	Output signal (mA)
230	7.6

Figure 97. Test result

It must be extracted the linear equation to convert the input signal to be able to know the voltage value in the monitoring system. The relation from the input and output values is shown in the next figure.

output range [mA]	0-20
Input range [A]	0-600
Relation output/input	lineal

Figure 98. features for the relation output/input

Knowing the general lineal equation:

$$y = m \cdot x - b$$

m value:

$$m = \frac{y_2 - y}{X_2 - X_1} = \frac{(20-0)}{10-0} = \frac{1}{30}$$

b value:

$$y = m \cdot x - b \rightarrow b = y - (m \cdot x) = 20 - \left(\frac{1}{30} \cdot 600\right) = 0$$

Finally:

$$y = m \cdot x - b \rightarrow x = \frac{y-b}{m} \rightarrow x = \frac{y-0}{1/30} \rightarrow \boldsymbol{x = 30y}$$

Where *x* = AC Voltage [V] and *y* = output signal [mA]

2.3.14. DC Intensity

The DC current intensity is not as easy to measure as AC current intensity due to DC current is a constant value instead an alternating value and that does not let to know the measurement in a directly way through a induced coil.

The sensor that becomes the DC current into a voltage signal is based also in a coil but in the other side of the sensor there is no coil. Instead that there is a hall sensor integrated in a suitable circuit to be able to measure it.

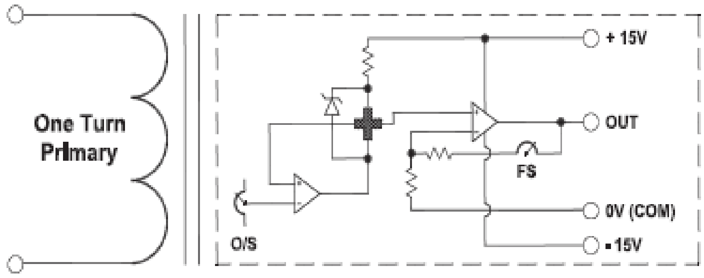

Figure 99. HCT_0010_010 schematic circuit

Categories	Current Transformers/Sensors
Reference	HCT-0010-010
Manufacturer/Brand	Magnelab
Series	HCT
Input Rating (A)	10
Standard Output	4 V
Input Type	DC
Output Type	DC
Error (%)	1.0
Power supply (V)	15
Current or Voltage	Voltage

Figure 100. Main features of de current sensor

The signal is give it in a suitable V signal.

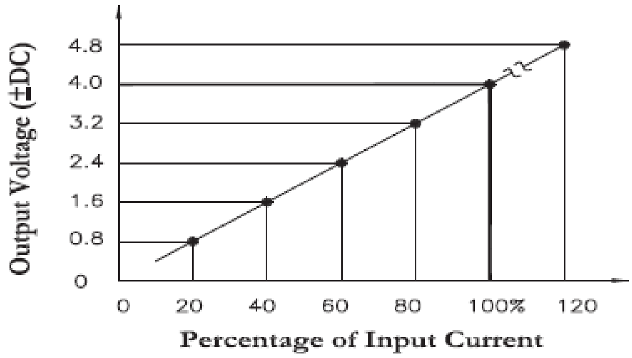

Figure 101. Relation between output and input signal

Looking at the datasheet it is found the relation between the output and the input signals, the last figure shows the lineal relation. It must be taken into account that 100% input make reference to a 10A according to the range of our sensor.

It must be extracted the linear equation to convert the input to know the current value in the monitoring system. It is possible to establish the relation from input and output values:

output range [V]	0-4
Input range [A]	0-10
Relation output/input	lineal

Figure 102. features for the relation output/input

Knowing the general lineal equation:

$$y = m \cdot x - b$$

m value:

$$m = \frac{y_2 - y}{X_2 - X_1} = \frac{4}{10 - 0} = 0.4$$

b value:

$$y = m \cdot x - b \rightarrow b = y - (m \cdot x) = 4 - (0.4 \cdot 10) = 0$$

Finally:

$$y = m \cdot x - b \rightarrow x = \frac{y - b}{m} \rightarrow x = \frac{y - 0}{0.4} \rightarrow \boldsymbol{x = 2.5y}$$

Where *x* = DC Current [A] and *y* = output signal [V]

The sensor well function was checked through an oscilloscope taking measurements from the same wire of the sensor. Another reference taken in account at the moment to check the value was the value displayed for the internal sensor of the inverter. The results were satisfactory and the error is tolerable.

Figure 103. Sensor placed and taking measurement with the oscilloscope clamp

2.3.15. DC Voltage

Sensor DVT_1000_V05 it is used for DC voltage measurement and is designed to convert DC Voltage input into 4-20m range signal or voltage standard output proportionally to the input. It is also perfect to be used in solar-string voltage monitoring. The transducer provides effective and safe isolation between the input and output. It is used 5 DC voltage sensors, one for each inverter.

Figure 104. DVT_1000_V05 being placed in the system

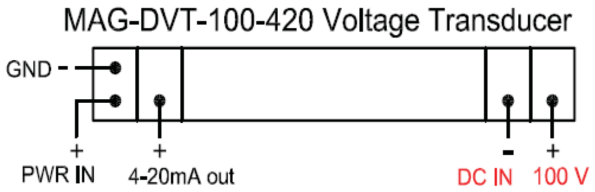

Figure 105. Connection scheme

Manufacturer	Magnelab
Reference	DVT_1000_V05
Input range (V)	0-1000
Output range (V)	0-5
Accuracy (%)	1
Relation output/input	Linear (0.5% over range)
Response time (ms)	10
Supply voltage (Vdc)	15-48

Figure 106. Main features

We must extract the linear equation to convert the input to be able to see the voltage value in our monitoring system. We can establish the relation from the input and output values:

output range [V]	0-5
Input range [V]	0-1000
Relation output/input	lineal

Figure 107. Features for the relation output/input

Knowing the general lineal equation:

$$y = m \cdot x - b$$

m value:

$$m = \frac{y_2 - y}{X_2 - X_1} = \frac{5 - 0}{1000 - 0} = \frac{1}{200}$$

b value:

$$y = m \cdot x - b \rightarrow b = y - (m \cdot x) = 1000 - \left(\frac{1}{200} \cdot 5\right) = 0$$

Finally:

$$y = m \cdot x - b \rightarrow x = \frac{y - b}{m} \rightarrow x = \frac{y - 0}{200} \rightarrow \boldsymbol{x = 200y}$$

Where *x* = DC voltage [V] and *y* = output signal [V]

The sensor was checked in the fixed place comparing the provided voltage values from the converter and through a voltmeter during different days. The result was the expected: it follows the calculated linear equation.

2.3.16. DC displays

To make a fast lecture of the current parameters were placed two displays per inverter that show the intensity and voltage that each prototype is giving to the inverters. These displays have no good accuracy but let to know a fast reading of the current features from the room where is placed the monitoring system.

Figure 108. Displays placed in the monitoring room

Both kinds of displays were tested taking a special attention to the current display due this one has to be calibrated in a specific way. These works are written up in the following lines.

Figure 109. Front and top view of the displays

The voltage display is the first device explained because it is the easiest to check and place.

Manufacturer	CHINT
Reference	PZ7777-1D
Range input [V]	0-660
Accuracy [%]	0.5
Power supply [V]	85-265 AC/DC

Figure 110. Main features of the voltage display

To check the display it was done in the laboratory the scheme showed in the next figure. Though a DC adjustable power source it was possible to do different tests.

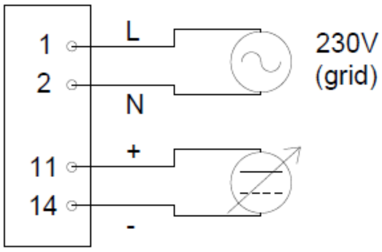

Figure 111. check scheme

Next figure shows how the voltage is measured correctly.

Figure 112. Laboratory test

This display takes current measurement in a particular way because it measures the voltage between a special resistors terminals and this difference of voltage it is treated by the device to show the equivalent current.

Manufacturer	CHINT
Reference	PA7777-1D
Range input [A]	0-15
Accuracy [%]	0.5
Power supply [V]	85-265 AC/DC

Figure 113. Main features of the voltage display

In last figure is showed the scheme that it was assembled in the laboratory to do the tests.

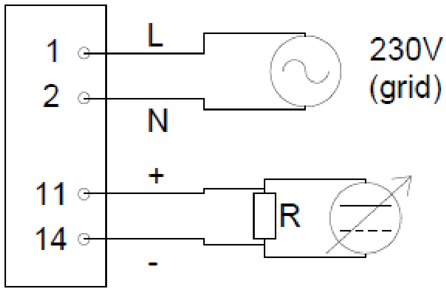

Figure 114. Test scheme

This way to take measure has the issue that is not possible to do a good calibration because it does not exist a huge quantity of special resistors. The first resistor that was checked was a 5mΩ and the results were not correct: for a real value of intensity about 150 mA the display showed just 90mA.

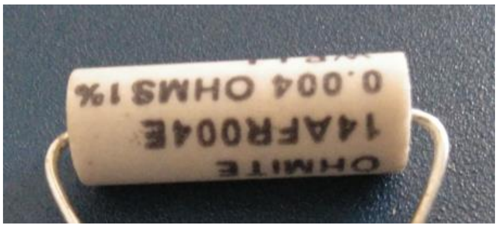

Figure 115. Resistant finally installed

It was asked for a 4mΩ resistor and this was also checked at the laboratory. In this new test the results were more suitable:

Real intensity [A]	Displayed value [A]	Error [%]
0.160	0.17	5.88
1.16	1.07	8.41
2.26	2.07	8.41
3	3.16	5

Figure 116. Results of the tests

Due the particularity of the resistant is interesting to see its features, they are showed in the next table.

.

Category	14A Series
Ohms Value	0.004
Watts	4.00
Ohms min	0.0040
Ohms max	0.051
Tolerance	1.00
Volts	0.450
TCR	150
Application	Current Sense
Construction	Element / Shunt
Resistor Mounting	Axial Lead

Figure 117. Main features of the installed resistor

2.3.17. Webeees

Webeee are devices developed and designed by Circutor with the objective to be used as a consumption analyser with a Wi-Fi connection that displays instantaneous and electricity consumption historical data through any smartphone device, tablet or PC by its app or built-in web server. It is really easy to install and it is available for single and three phases.

Figure 118. Webeee installed

Technical features		
Power circuit	Connection type	Single or three-phase
	Voltage range	85...265 Vac
	Frequency	50 - 60 Hz
	Consumption	17 mA
Measurement circuit	Rated voltage	85...265 Vp-n
	Nominal current	70 A (16 mm²)
Accuracy class	Voltage	2%
	Current	2%
Communications	Type	Wi-Fi (**IEEE 802.11**)
	Protocol	HTTP, Modbus/TCP, XML
	Frequency range	2,405 - 2,480 GHz
	Encryption	AES128
	Certification	**FCC (USA), IC (CANADA), ETSI (EUROPE)**
Build features	Enclosure material	Self-extinguishing **UNE 21031** 90 °C
	Protection degree	IP 20
Environmental conditions	Operating temperature	-25...+45 °C
	Humidity (non-condensing)	5 ... 95% (non-condensing)
	Maximum altitude	2,000 m
Safety	**IEC 61010-1:2001** Double-insulated electric shock protection class II	
Standards	**UNE-EN 61010-2-030:2011, UNE-EN 61326-1:2006, EN 301 489-17 V2.2.1**	

Figure 119. Datasheet

At the moment of this writing are installed four of them to take measurement of S1, S2, S3 and S4 energy production. During the installation some issues happened because the building Wi-Fi system is not suitable for this device, to solve that it was installed a router with a name user and password. The password and the Wi-Fi name are attached on the backside of the door at the room where the monitoring system is.

Wi-Fi name	TR14ANAPOT
Password	Quig3fa3ichiYu1

Figure 120. Name and password Wi-Fi used

Once the devices were configured and the account created it was possible to see many parameters like individual and collective dairy, weekly or monthly production as well as all the current parameters from each device in an instantaneous way. All of these functions are available through the website or by the app that it is possible to be downloaded on a smartphone or tablet.

Figure 121. Example of what is possible to see in the website

2.3.18. Omnik Portal

The inverted installed are also able to take measurement and recollection data of production energy parameters and current parameters. These measurements and data collection can be monitored and shared with other people around the world through the website “Omnik portal”. This portal is property of the same manufacturer of the inverters (Omnik) and is completely free. Our power system is registered and configured with the name “UPC”.

User	ket.supply.upc@gmail.com
password	upcsudoket
Power plant name	UPC

Figure 122. Account name and password

Figure 123. Website view

2.4. SOLAR INVERTER

PV panels must be managed by an external system to reach they give the maximum power as well as to condition the PV current output properties to the grid properties.

The inverter is the component that manages the energy of the PV panel and turns DC current into AC current to be given to the grid, it is also important to remember that the inverter has to give the AC current synchronized with the phase of the grid. This component is one of the main components needed to be able to take the energy from the sun and be used because the PV panels give DC current and it is not useful for feed an electrical system as buildings or similar.

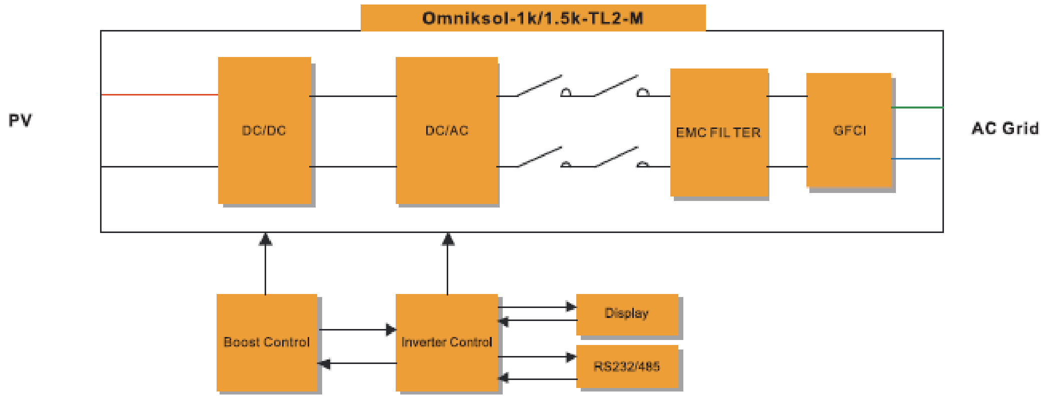

Figure 124. General scheme of the used inverter

The inverter used has also and internal EMC filter to eliminate issues with electromagnetic fields and a GFCI to protect itself. It is also capable to give information about the energy managed by Wi-Fi to a computer.

Because of five group of PV panel (S1, S2, S3, S4 and S5) are being studied, five inverters are also needed in order to be able to know how many energy and which features the energy has from each one.

The inverters don't need to be programmed or set before the starting up. The only think needed is to connect the inverter and the grid in the correct way. The inverters have a display in what it is possible to see the features from the current processed as well as some inverter features like the software version or the owner reference. However, to be able to have communication with them and recollect data it must be placed and configured the communication card. The process it is not intuitive and it is needed to follow the described steps in the owner manual available in its website. In the process it is needed a computer with Wi-Fi connection and know the name and Wi-Fi password available in the room and in this project:

Wi-Fi name	TR14ANAPOT
Password	Quig3fa3ichiYu1

Type	Omniksol-1k-TL2-M
Input(DC)	
Max. PV Module Power [W]	1250
Max. DC Voltage [V]	500
Nominal DC Voltage [V]	360
Operating MPPT Voltage Range [V]	60 - 400
MPPT Voltage Range at Nominal	155 - 400
Start up DC Voltage [V]	70
Turn off DC Voltage [V]	50
Max. DC Current [A]	10
Max. Short Circuit Current [A]	12
Number of MPP trackers	1
Number of DC Connection	1
DC Connection Type	Amphenol Connector
Output(AC)	
Max. AC Appaeent Power [VA]	1100
Nominal AC Power [W]	1000
Nominal Grid Voltage [V]	220 / 230 / 240
Nominal Grid Frequency [Hz]	50 / 60
Max. AC Current [A]	5
Grid Voltage Range [V]*	185 - 276
Grid Frequency Range [Hz]*	45 - 55 / 55 - 65
Power Factor	0.8i - 0.8c
Total Harmonic Distortion (THD)	<3%
Night time Power Consumption [W]	<1
AC Connection Type	Plug-in connector
Efficiency	
Max. Efficiency	96.5%
Euro Efficiency	95.8%
MPPT Efficiency	99.9%
Safety and Protection	

Figure 125. Main features of the inverters

Once the communication software is configured it is possible to do a tracing of the energy and manage the power using the portal available in Omnik website that it is described in the chapter 2.3.18 of this project.

Figure 126. The inverters being placed

2.5. STORAGE SYSTEM

The storage system was provided by Circe which is a member of Sudoket project. The storage system has a capacity of 10kW and it has its own inverter and managing system integrated to manage or store the energy. The storage system has an easy connection and it is placed at the monitoring room.

Figure 127. Image of the storage system

GENERAL SPECIFICATIONS	
GENERAL:	
Max. Power	10 kW
Max Operating temperature	-20 to 50°C
Communication interfaces	RS-485 x2, CAN x2
Battery Communication	BMS - Battery Management System
Communication parameters	TBD
Protections	- Over-voltage and Under-voltage in the battery side - Over-current in the battery side - Transistor short-circuit and desaturation - Power electronics over-temperature - DC-link over-voltage and under-voltage - DSP and coms. watchdog
Safety & EMC	- Prepared for CEM Electromagnetic Compatibility 2004/108/CE

Figure 128. Main features of the storage system

The storage system let the system to stock energy when the PV energy production is higher than the consumption and then uses that energy when the production is lower. Because of the energy is never sold to the company and is given for free, the storage system let us to take more advantage of the energy production.

2.6. COMMUNICATION SYSTEM

The communication system manages all the information of the sensors and sends them to the computer to be saved and compiled in a useful way by the software programed.

The signals given by all sensors of the system are read by "LabVIEW". The signals are not directly sent into the computer that hosts the software but they are manipulated and sent by the communication system. Here is presented the track that the signals take from the terrace to the computer.

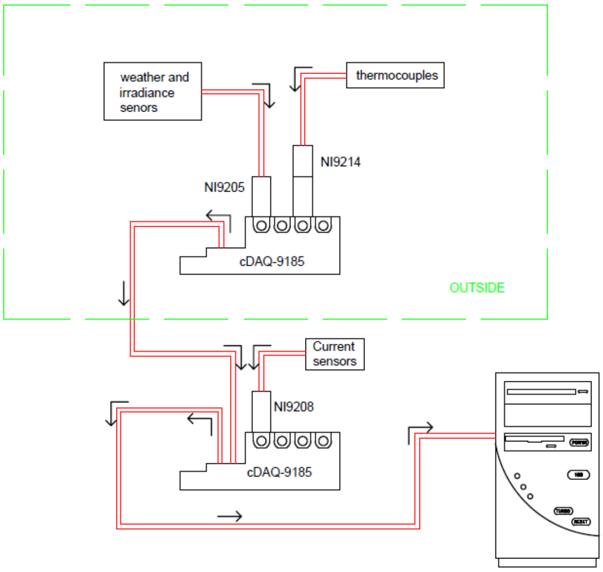

Figure 129. Scheme of the communication system

2.6.1. cDAQ-9185

It is the base used for the exchange and signal distribution sensor to the computer. This base manages the time, synchronization and the data transference between the modules and the external server (PC). It is possible to use analogic, digital and temporal signals. It needs to be fed through its own power source.

Figure 130. cDAQ-9185

Two of them are used, one is placed outside in the main box and it is recollecting data from weather and irradiance sensors and the other one is placed inside in the box near the computer and recollects and send the data from current sensors to the computer as well as being used like a bridge between the outside base and the computer. The signals are sent through a “lan” wire and NI9214 and TB-9214.

The NI9214 is a high-density thermocouple module for CompactDAQ and CompactRIO Systems. It is designed for use in higher-channel-count systems that also need high accuracy. The NI9214 increases overall accuracy with a front-mount terminal block (TB-9214), several CJC sensors in the terminal block and a component layout that minimizes thermal gradients. It is possible to connect up to 16 thermocouples.

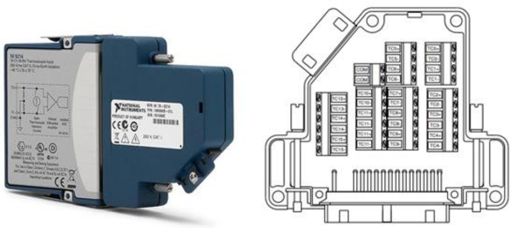

Figure 131. NI9214 and TB-9214 put together (left) and input connections (right)

The signal thermocouple is directly processed and turned into signal temperature by the National Instruments software setting in the software the thermocouple connected.

It is also connected the external temperature and humidity sensor because NI9205 has not enough inputs for all the weather and irradiance sensors. Due to the fact that these sensors send current signals is necessary to turn each signal into voltage. The way to reach that is collecting the voltage that a known resistant provokes when the current crosses it. The resistor used is 3,33Ω (three 10Ω resistors connected in parallel) and the signal range is 4-20 mA so the range of the new signal is 13.32-66.6 mV and it has to be set in the software.

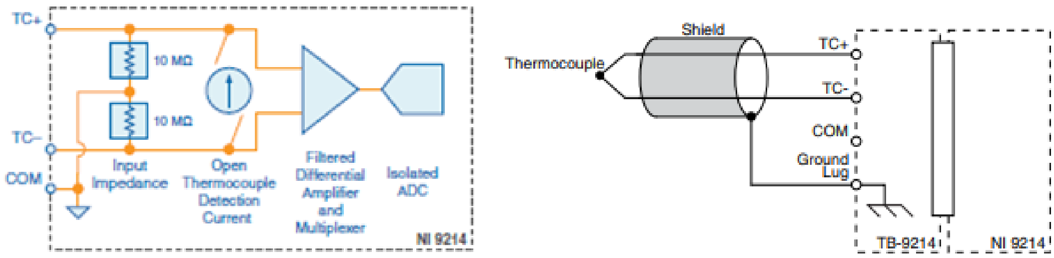

Figure 132. Connection scheme

The thermocouples are connected in the inputs showed in the next figure.

Channel input	**sensor name**
0	TF_HR_CH0
1	TC_S41_CH1
2	TC_S21_CH2
3	TF_S4_CH3
4	TF_CH4
5	TF_S2_CH5
6	TC_S3_CH6
7	TC_S1_CH7
8	TC_S5_CH8
9	TC_S22_CH9
10	KFTF-I (Temperature)
11	KFTF-I (Humidity)
12	TC_S42_CH12

Figure 133. Channel connection

2.6.2. NI9205

NI 9205 is a C Series module for use with any CompactDAQ or CompactRIO system. Each channel has programmable input ranges of ±200 mV, ±1 V, ±5 V and ±10 V. To protect against signal transients the NI 9205 includes ±30 V of overvoltage protection between input channels and common (COM). In addition the NI9205 also includes a channel-to-earth ground isolation barrier for safety, noise immunity and high common-mode voltage range. It is possible to connect 16 sensor in differential way or 32 sensors in a single-ended way.

NI9205 is placed outside and the weather and irradiance sensors are connected to it.

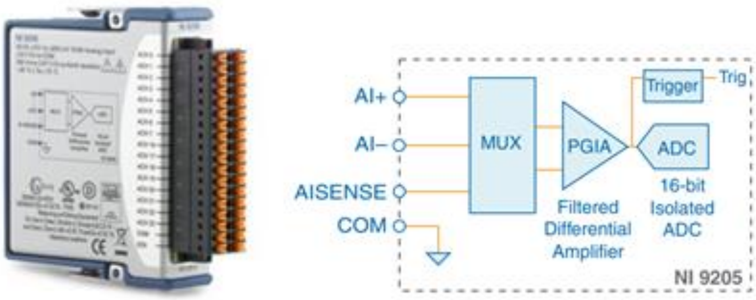

Figure 134. NI 9205 and its internal scheme

Channel input	sensor name
0	MS80A
1	MS65
2	MS40A
3	MS40A [E]
4	MS40A [W]
5	ML_813
6	ML_742
7	ML_745
8	ML_743
9	ML_741
10	ML_744
11	ML_814
12	ML_811
13	ML_812
14	ML_740
15	Seneca_Z111

Figure 135. Channel connection

2.6.3. NI9208

This component lets to collect the current signals in the range between ±20mA. It has 16 channels and it is placed inside the monitoring room and it is used for collect data from current features as intensity and voltage from both DC and AC currents.

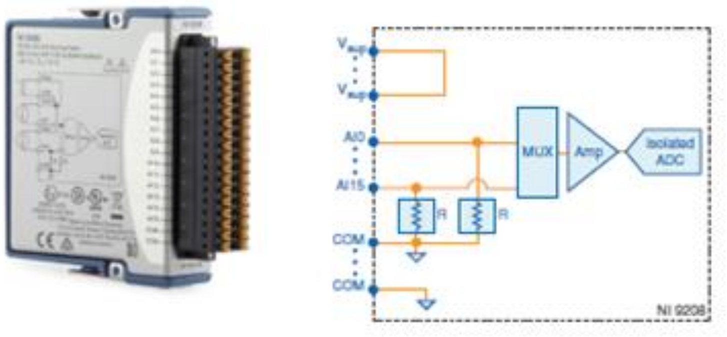

Figure 136.NI 9208 and internal scheme

The input signals are scanned, amplified, conditioned and then sampled by a single 24-bitADC. The module provides overvoltage protection for each channel.

Channel input	Feature
0	Idc_1
1	Idc_2
2	Idc_3
3	Idc_4
4	Idc_5
5	-
6	Vdc_1
7	Vdc_3
8	Iac_1
9	Iac_2
10	Iac_3
11	Iac_4
12	Iac_5
13	-
14	Vdc_2
15	Vdc_4
16	Vdc_5

Figure 137. Channel connection (see 2.4 section)

2.7. ELECTRIC CIRCUIT

It must be differentiated two important electric circuits: the collecting data system and the power generation system.

The collecting data works with voltages about some mV up to 48V in the most powerful source that is used to feed the recollecting data components. However, this system also manages higher voltages because it is also recollected the features from the power generation system that have voltage values up to 100V in the DC side.

The system it is shown in two steps: firstly it is analysed the main scheme and then each part of system is focused, which are separated in boxes.

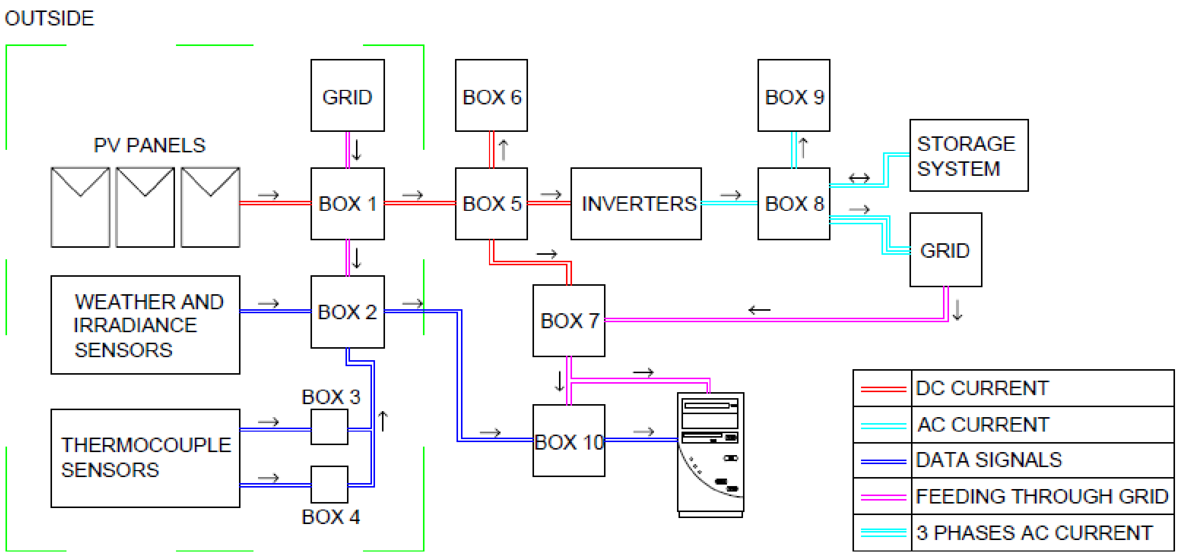

Figure 138. Electric scheme of the whole system

In the scheme is not showed all the wires, instead of that are eliminated the ground wires and specific features like distinctions between neutral and phase or negative and positive.

- Box 1:

It is placed outside near the weather sensors and inside itself it is found the outside protections for the PV panels (fuses) as well as the energy output to the box 2 (under protection). It is also placed a non-used plug.

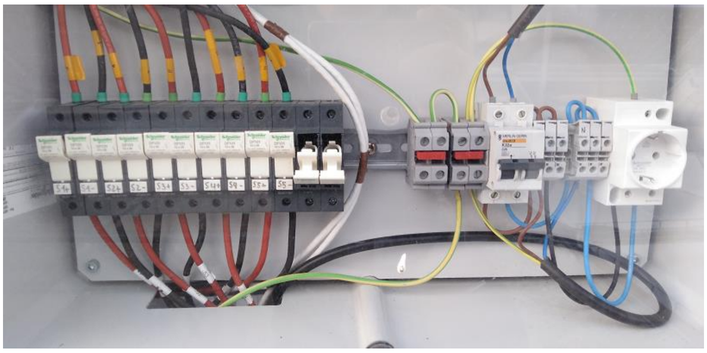

Figure 139. Inside of Box 1

- Box 2:

The box 2 is the main box placed outside, here it is placed the cDAQ-9185 that collect all the signals from outside through NI9214 and NI9205. In this box is where the wires of all the sensors placed outside end and also where it is placed the converters, feeding sources and protections to manage all of components.

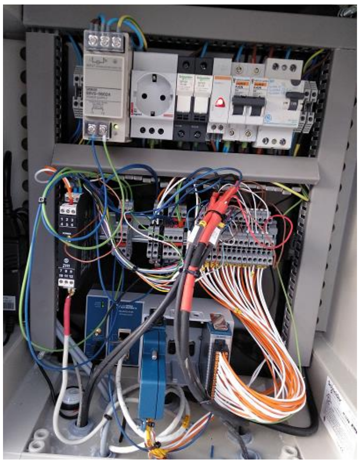

Figure 140. Inside of Box 2

- Box 3 and 4:

These boxes are just splices between the albedo sensors and the Box 2. There is one of them fixed on the frame of S2 prototype and another one on the S3 frame.

Figure 141. Box 3 and 4

- Box 5:

It is the main protection box and it is placed inside. It is the box in the top of the wall. Here it is placed PV protection against short circuits and over tensions. The over protections used are the component named PSM-40/1000 made by Cirprotec.

Figure 142. Inside of Box 5

- Box 6:

It is placed inside, between box 7 and box 9 and has the purpose of led us to do test and measurements over the DC production through external devices from the system, that it is possible due a standard plugs installed on it that are connected with each prototype and the storage system. These plugs are protected by fuses avoiding short circuits and other possible accidents.

Figure 143. Box 6

- Box 7:

It is placed inside, near the communication system (box 10) and it is used to show the DC voltage and current through several displays. The purpose of this box is led to know DC features in an immediately way. It is also placed the protection that feed the box 10 and the computer.

Figure 144. Box 7

- Box 8:

This is the main box for the AC side. Box 8 distributes the energy from the inverters between the grid and the storage system. The energy can go also from the storage system to the grid depending on the PV production and grid consumption. In this box is also found several protections as well as the Webeees that recollect electric data features and send them to the Webeee portal. It is placed inside, below the inverters.

Figure 145. Box 8

- Box 9:

It is placed inside, between box 8 and box 6 and has the purpose of led to do tests and measurements over the AC current through external devices from the system, that it is possible due a standard plugs installed on it that are connected with each phase and the neutral. These plugs are protected by fuses avoiding short circuits and other possible accidents.

Figure 146. Box 9

- Box 10:

It is the main box for the communication system, here it is placed the cDAQ-9185 that receive all the signals to be managed by the software. Some sensors, DC power supplies and protections to manage all of components are also placed here.

Figure 147. Inside of box 10

2.8. LABVIEW PROGRAMING

Software is nowadays the most important matter in any project of modern engineering, or in most cases, is the director and the way to let us be able to manage all the components. The software and the digital technology is what make differences between old and new technologies.

Several software like Matlab and AutoCAD have been used to help in this project developing process but the most outstanding software in this case is the one used to manage all the monitoring system: LabVIEW, developed by National Instruments with the purpose of give supporting for applications that require test, measurement, and control with rapid access to hardware and data insights. It has been used the 2017 version included in the NI package Manager 2017. Package that it is needed to be able to engage the devices also obtained from National Instruments and related in the chapter 2.6 from this project.

In this chapter is listed and explained all the programs programed from LabVIEW to lead the system. Most of them created and exclusively developed for this project.

2.8.1. Common particularities

Before showing the programs in the following paragraphs it is explained some of the particularities and functions from LabVIEW program in order to make an easier understanding of them. Due the complexity of the LabVIEW it is not possible to do a user manual but this can be a useful first guide.

LabVIEW it is managed by two windows in what one of them is used for programming and the other one is used to make the layout where the interaction between the user and the program happens once it is finished. In this section it is related and explained mainly the programing window because this one show the real program and all the commands integrated in this side has a direct effect in the other window. Only the actions relatives to esthetical functions are not affected in the programming window.

- Start and Stop:

LabVIEW has a function to stop the programs inside its main commands but it is not suitable to be used because do not actually stop the program that it has been designed through LabVIEW but it just makes a pause remaining the last step, code or value processed in the memory and resting to the click in the start button, so to get a real stop it must be used the stop block available to be integrated in the program designed. The stop block integration in the main window entails the appearance of a stop bottom to be used in the way explained.

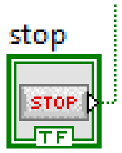

Figure 148. Stop block

- While loop:

The programs must be inside a while loop in order to take control of the numbers and iteration duration.

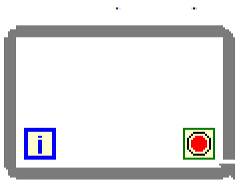

Figure 149. while loop

Its placement means having a stop (explained in last paragraph) and iteration block. The iteration block is usually managed from a wait block that is accompanied by a timer value that defines how long the program is stopped since the next iteration.

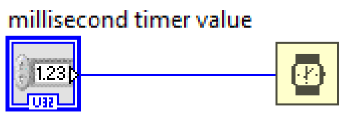

Figure 150. regular way to manage the iterations

- Date block

It is very useful and also compulsory that the program know the date because it will be working during days, months or years and the final study is based on how the system performance changes along the time. So the data must be accompanied by the date that it has been taken. Although the program is able to know the date by itself it is useful to show and be able to use the date in order to design the program and know in what moment of the day we want to stop, restart or save anything. With this purpose it is integrated the date block.

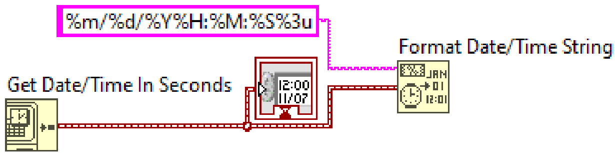

Figure 151. Date block and it treatment

- DAQ assistant

This block has the purpose of establish the communication between the cDAQ-9185 base related in the section "2.6.1 of this project" and the LabVIEW. Many properties like the channel, range and number of samples of each signal managed has to be configured.

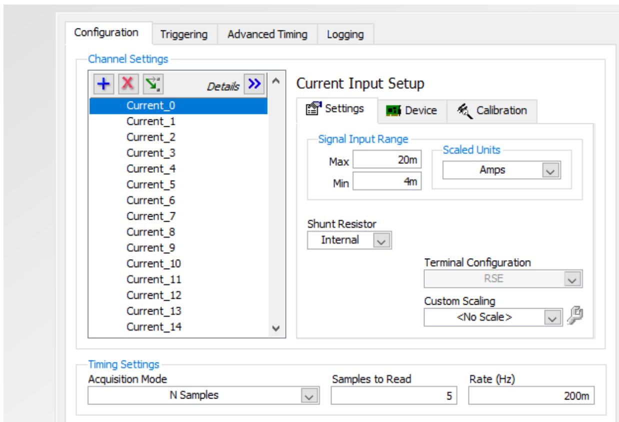

Figure 152. Example of configuration

This block can be accompanied by numeric controls and indications in order to define configurations relative to the signals parameters like the quantity or the samples rate.

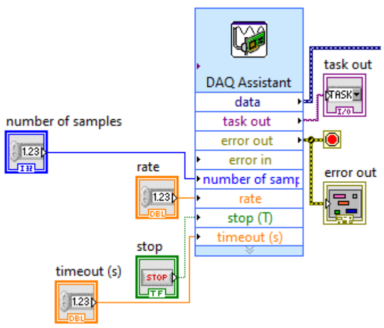

Figure 153. DAQ assistant

- Data treatment:

In most cases data must be saved to be able to make a study and analysis of them. It is possible to use the data treatment block existing in LabVIEW to help us in this purposes. This block has an easy configuration in what it has to be defined setting as the file format and the folder where the data is going to be saved.

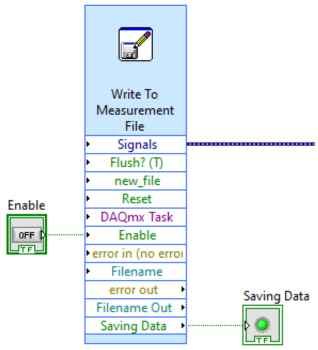

Figure 154. Data treatment block

- Signal treatment:

As it has been seen in the section 2.3 the sensors measurements sensors are given in voltage or current signal, to be able to see the value that represent have to be processed in most cases multiplying or dividing them by a number depending on the lineal relation between de output and the input signal.

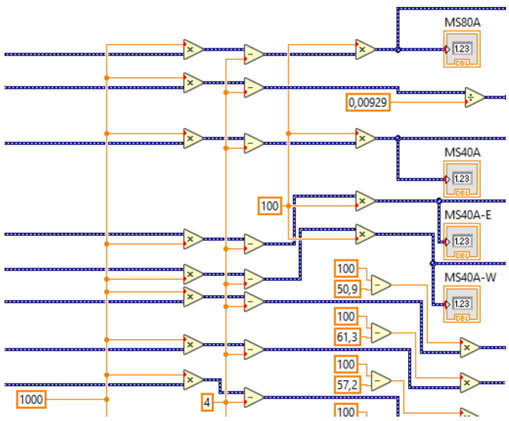

Figure 155. Irradiance signal treatment

- Numeric controls, indicators and graphics

These blocks are used to let the user interact with the software. Its placement in the window destined for programing creates automatically another block in the second panel with and appearance that depends on the type of block that it is used. Blocks like indicators or plots just display information in the panel and can be showed in many ways as a bar plot and a lineal plot if we are speaking about graphics, or as a number or a progress bar if we are speaking about indicators.

Numeric control blocks let the user modify parameters that can affect to the program in many ways like numbers of iterations of the running program or number value to be processed by some program function.

LabVIEW allows doing the project layout in nearly infinite configurations of colours and visual designs just like it is shown in the programs that are explained in this section.

2.8.2. Photovoltaic cell characterisation

This program has been designed and downloaded from National Instruments website and afterwards modified by us giving to it a new appearance with a regular design used by UPC like colours and logos.

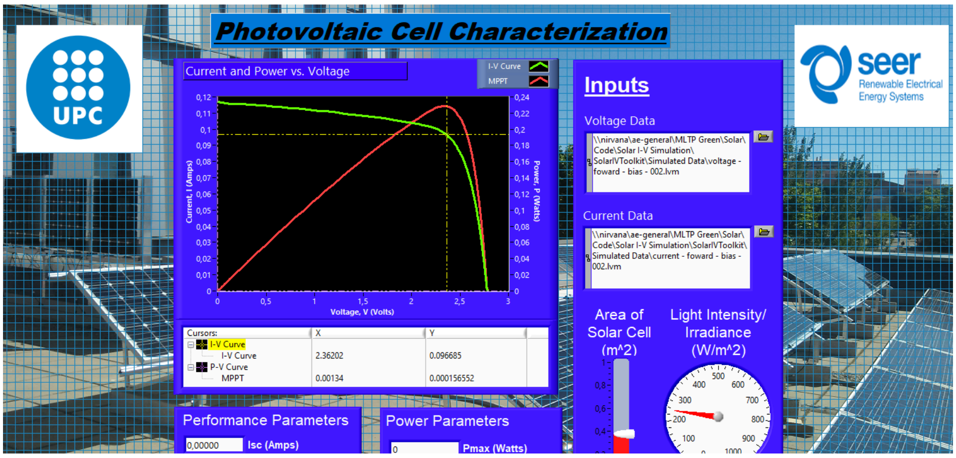

Figure 156. Final program appearance

This program has the purpose of plotting the V-I and MPP curve from the PV panels through data files. It is possible to know the cell characterisation taking measurement of the current and voltage data as well as the irradiance that there was in the measurement moment.

The way that it has been used is checking the plots obtained from the device Solar I-Ve as it has been explained in the chapter “2.2.2 PV Panels characterisation” of this project. Using the data obtained the results were checked again verifying the program well working.

It is relevant to comment that the file data has to be modified using the program Notepad because the file extension of the data file required is not allow to be opened by most of the programs.

2.8.3. Irradiance displaying

Program designed with the purpose of checking the irradiance sensors function and make calibrations just in case to be needed. The program recollects the signal from the sensors, treat them and show the irradiance instant value as well as saving data by an Excel file every period of time selected by the user. It is also possible to choice not to create the file and just show the irradiance.

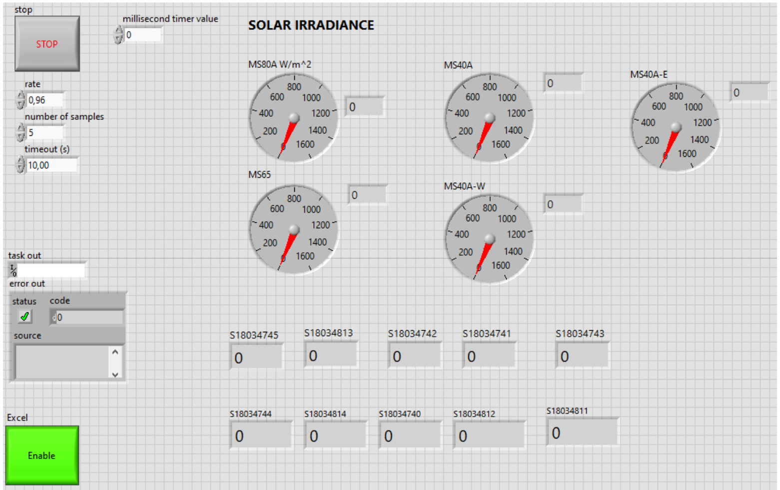

Figure 157. Program appearance

This program was used during the sensors calibration before the final installation of them and it can be used again but. The structure of this program was used to do next programs.

2.8.4. Thermocouple and weather sensor checking

It an easy and simple program that allows checking the thermocouple signals as well as the humidity and the signal weather temperature.

The thermocouple signal is automatically processed by LabVIEW that let to know the temperature from signal in a direct way, without implementing blocks in the designed program for that purpose. The signals from humidity and temperature sensors are shown in the way that is given by them: mV. All signals are also shown together in a graphic. This program structure was used to do next programs.

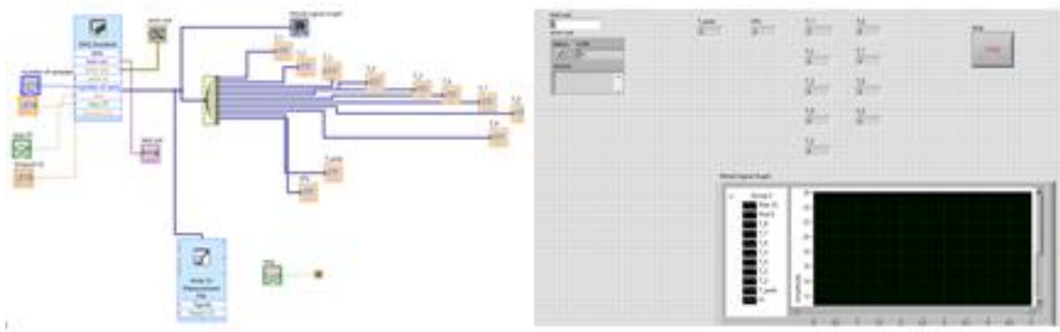

Figure 158. Both panels from the program

2.8.5. Monitoring program

This program makes the system monitoring. Inside it is implemented, modified and complemented the programs that has been previously displayed reaching an instantly visualization of the system state. No sensor showed in the section "2.3 sensors" is forgotten: thermocouples, irradiance, weather, dc current and voltage… all values are also saved in an excel file to allow a study during the time.

Regarding the layout panel destined to display the information, the monitoring program has been designed to let the interoperation of values without using other documents such as technical plans or schemes about the placement of panels or sensors. To get this the layout has been designed using draws that simulate the terrace appearance as well as the real placement of the sensors and panels.

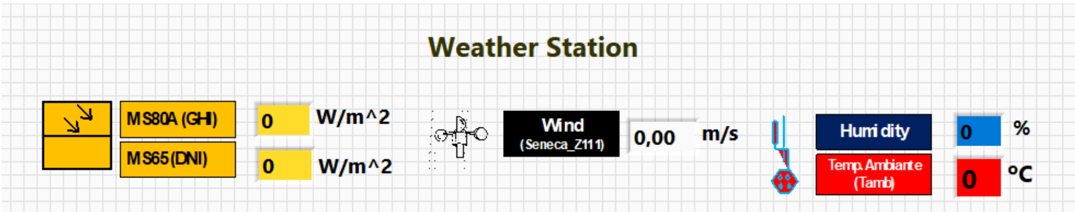

Figure 159. Monitoring program fragment

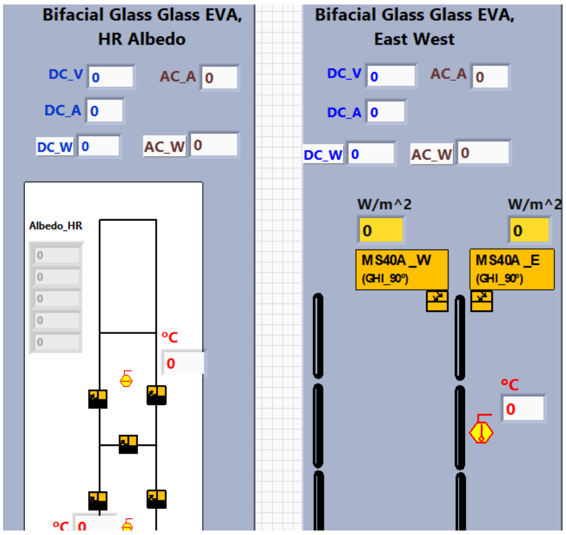

Figure 160. Monitoring program fragment

2.8.6. Performance monitoring

This program has an important purpose in the project because it will be possible to do a monitoring an evaluation of each prototype performance through it. To do this task the program is able to do the whole system monitoring like the last program that it has been seen and also shows and save information about the energy production during each day, week, month and year from each prototype as well as from each inverter in order to do a reliable study about the efficiency of the system paying special attention in factors like panels degradations and the placement. For all that this program is also the most complex and difficult because it must manage the time to do a suitable recording data, which must not be affected by problems like possible computer or system disconnections.

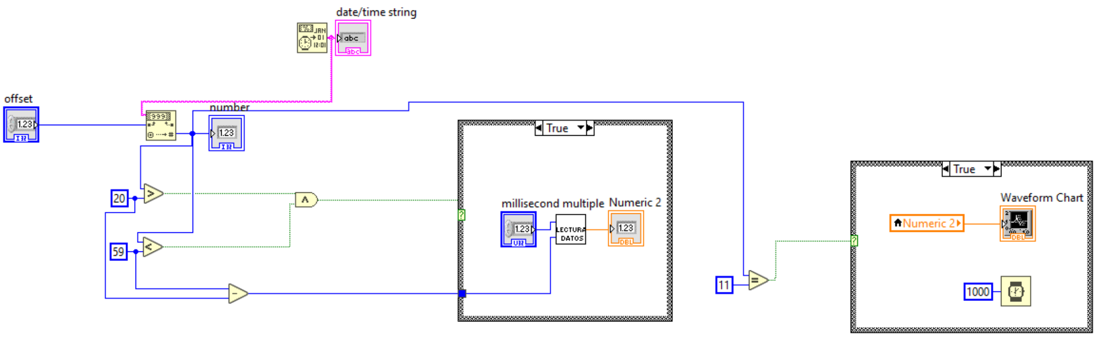

Figure 161. Time managing example for the plotting

To programme this software has been followed the British standard for photovoltaic system performance monitoring that establishes the guidelines for measurement, data exchange and analyses in that subject (BS EN 61724:1998 and IEC 61724:1998).

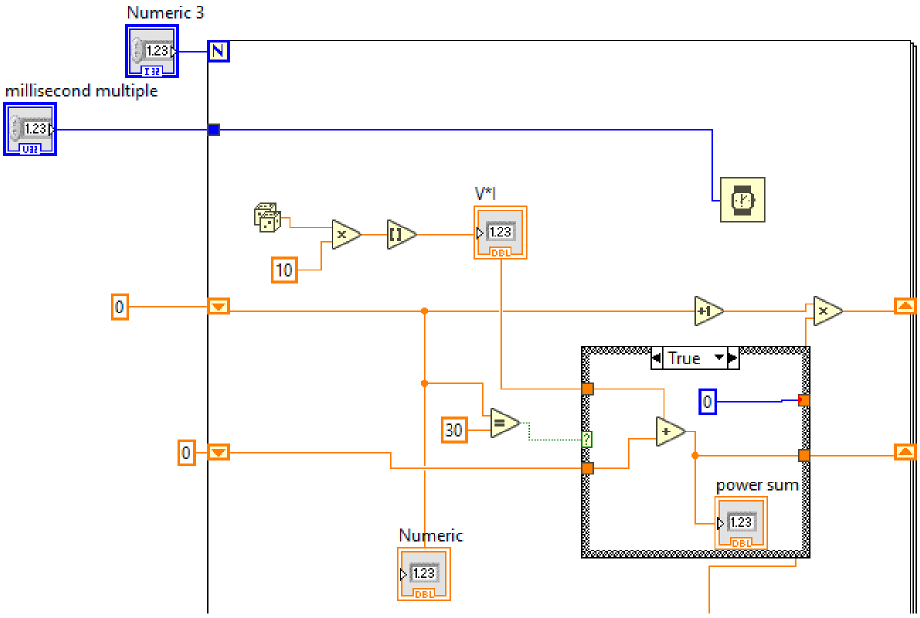

Figure 162. Program example that do the energy measurement according the BS

CHAPTER 3. SETBACKS, PROBLEMS AND SOLUTIONS

During the development of the project it has been occurred some issues because of several factors not possible to be controlled or to have into account before the starting up due to the complexity and the huge quantity of topics to treat. The project involves a lot of people, companies, devices and components that requires synchronization and availability not possible to reach unless allowing the possibility of mistakes and setbacks that can be solved by wide timeframes. In this chapter is explained the setbacks, problems and solutions performed.

3.1. PV PANEL MALFUNCTION

This issue has been seen in the section “2.2. PV panel features” but it is such an important problem to be also summarized in this chapter as well as being placed in the first section of this chapter.

In the mentioned section it has been explained that the MPP check and temperature tests show that the panels were not working in a correct way as well as visual inspections let see a premature degradation of the encapsulation.

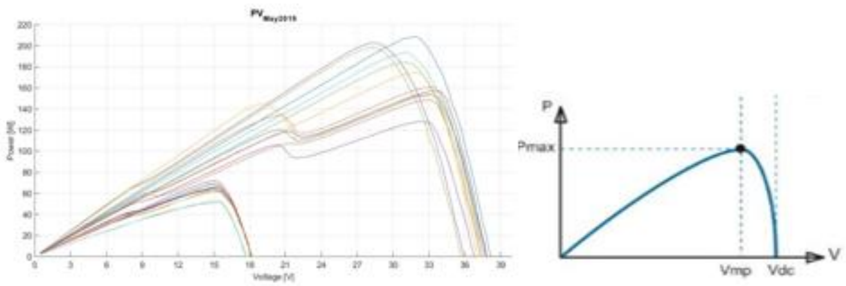

Figure 163. Obtained MPPT (left) and correct MPPT (right)

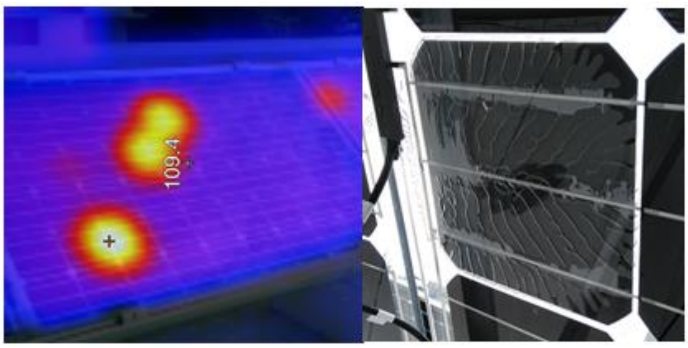

Figure 164. Hot spots and encapsulation degradation

After doing the report and send it to the PV panels responsible the conclusion was that the PV panels have to be replaced. The next step is removing the PV panels installed and placing the news ones which have similar properties. It will be also necessary new tests and set of the system (software, sensors placements…) in order to reach the best suitable monitoring of them.

Figure 165. New PV panels

3.2. INVERTERS MALFUNCTION

As we have seen in the section 2.4 the inverter is the component that manages the energy from PV panels and turns DC current into AC current to be given to the grid and makes the PV panel always working in the MPP in order to reach the maximum panel energy in every moment as possible as the irradiation allows.

During the system test it was seen some problems with the inverters because sometimes the inverters stopped and the energy production was 0 until doing the inverter reset. Another problem seen is that the inverters were not working in the PV panels MPP. After asking for solutions to technical assistance as well as the people in charge of the inverter system (inside the Sudoket program) the first step took was doing an upgrading of the inverter software. To do it is needed the RS485 card as well as the upgrade file supplied by the maker. The upgrading process is easy to do. The inverter has to be off and the wires from the PV panels disconnected, then it has to be inserted inside the RS485 card a microSD card with the upgrading file. Then RS485 has to be placed inside the gap destined for the Wi-Fi card. The last step is turning the inverter on and wait until the process showed in the inverter display is done. To finish the process the inverter has to be turned off and the RS485 card replaced by the Wi-Fi card. At the moment of write this project the issues appear to be solved.

3.3. WAITING TIMES AND REPORT WRITING

On the one hand, the amount of companies and universities involved in this project has caused the need of communication between them by emails and reports in order to solve issues as well as to ask for information, components or instructions. On the other hand most of the components had been ordered to commercial companies and brands that have their own delivery time.

It is for all these factors that have been appeared waiting times. The need of write reports as well as the test repetition through several ways or devices in order to satisfy the requirements of the external companies or brands has increased the waiting times.

3.4. COMPONENTS AND DEVICES PLACEMENT

The component placement is not trivial, it is needed a previous study about sensors to find the most suitable position regarding several factors like inclination angle, datasheet or the place available.

For example it has been also necessary to do several redistributions of the components inside the boxes in order to find the best setup of them to let us to modify and manipulate the components in the easier way as well as present them in a clear way.

Some components and devices like irradiance sensor or thermocouples needed handmade supports to be placed.

3.5. COMPONENTS CALIBRATION, TESTING AND FIRST STARTING UP

The steps mentioned in the title of this section could seem easy and fast to do, but these have delayed the process because of several setbacks that have been appeared along the calibration, testing and first starting up of some components of the system. The main issues can be summarized in:

- Setbacks and issues that have been caused because of lack of experience about sensors and software used in the project, especially in this last one. These issues have been solved through repeating test in the laboratory and finding information on internet and books. It was also a great help to ask to teachers from the university that kindly have taught me about the matters that have been appeared along the project.

- Some sensors and sensors components like converters have no manual or datasheet because those have been reused from previous projects so they are too older to find datasheet in maker websites due to the fact that they are obsolete although completely useful. To solve this problem and know how to connect and test them it was needed to ask to the staff that participated in previous projects. The schemes found and their properties are included in this project in the every sensor chapter.

CHAPTER 4. CONCLUSION

The real project in what I have been involved is not completely finished due external factors and because this project also means a monitoring and study of the solar photovoltaic system during several years in order to take conclusions about the technologies subject to study

In spite of that it is possible to extract conclusions about my personal project that is located within the installation framework of all the devices and components required to manage the future monitoring. Framework that is big enough to be part of a final degree project as it has been seen along this report.

I have wanted to separate two different conclusions that could be extracted from the project.

4.1. NEW THECNOLOGIES DEVELOPMENT CONCLUTIONS

Although the photovoltaic technologies are known about forty years ago is not since the last ten years that the interest about it has been increased due a factors like the climate alarm warning and the concern about taking care of the planet, setting aside non-renewable ways of energy production and raising the interest about renewable energy.

This last has caused that nowadays the investigation about renewable technologies is something new and there is huge possibilities of investigations that require big investments to acquire the most suitable performance of them. This fact also induces new sensors and devices development to be able to do these studies and here is where we have realized about how the industry has grown to support the new raising market. The researches have a lot of work to do and teach in this new field. This also situation explains the issues redacted in the chapter 3.

4.2. PERSONAL CONCLUSIONS

The development of a project that involves new technologies and fields needs staff able to continuously be learning about the new components, devices and software that are required to research them. Because of the previously said, working in a project inside the engineer field is more complex that it would seem. Many people and companies are involve in them and require a lot of experience as well as generous deadlines to allow solving the issues and setbacks.

I would like to finish the conclusion of this project speaking about the contributions that it has feed my growth in the professional and academic fields. It has been great and suitable choosing a final project for me bachelor's degree like this, where I have been able to manage it taking some responsibilities that depends on my abilities and knowledge supposed to be achieved in the degree, so it is really possibility to see that the project has been a challenge as much as a training for my future as an engineer, without forget the fact that being written in English has also been the most suitable way.

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